ICHEP 2014

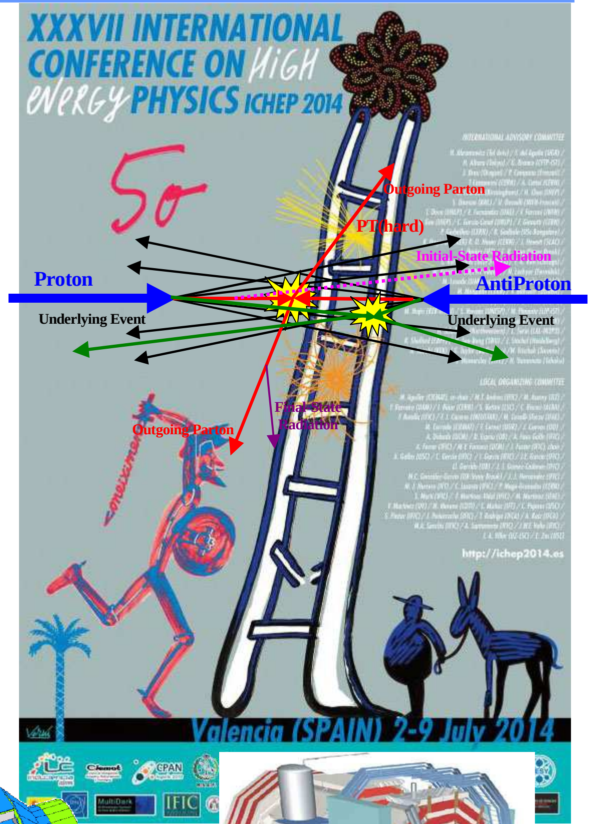
Tevatron Energy Scan: Findings & Surprises

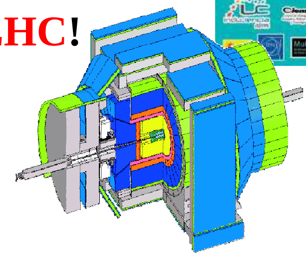
Rick Field
University of Florida

Quantum
Chromo-
Dynamics

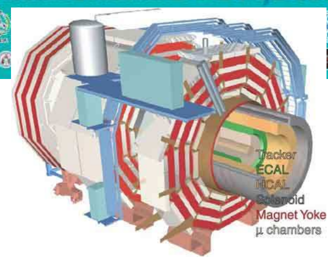
Outline of Talk

- **CDF data from the Tevatron Energy Scan.**
- **The overall event topology for events with at least 1 charged particle.**
- **The "transMAX", "transMIN", "transAVE" and "transDIF" UE observables.**
- **Mapping out the energy dependence: Tevatron to the LHC!**
- **Comparisions with the new PYTHIA 8 tunes: CMS Tune CUETP8S1-CTEQ6L and Skands Monash Tune.**
- **The UE and DPS.**
- **Summary & Conclusions.**



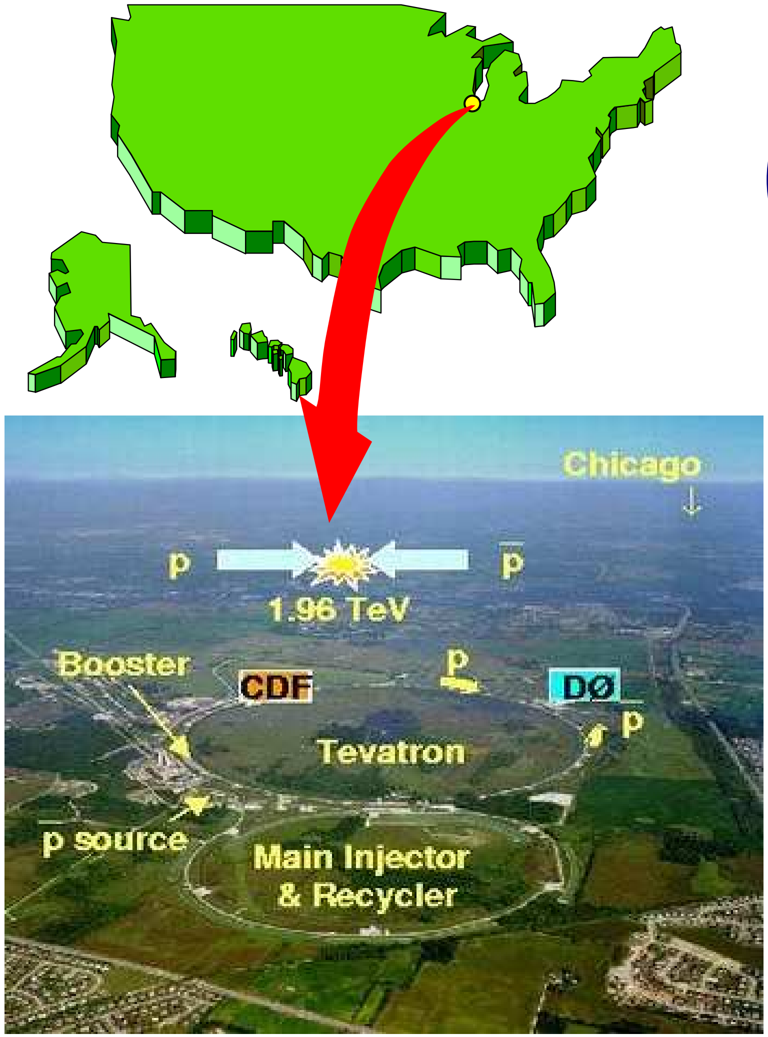


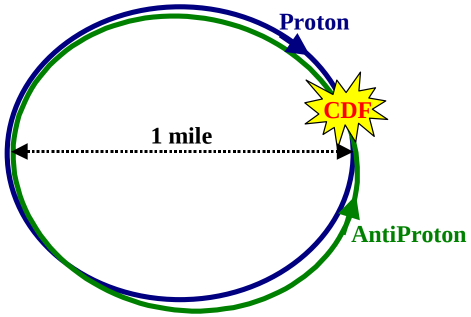
CDF Run 2
300 GeV, 900 GeV, 1.96 TeV

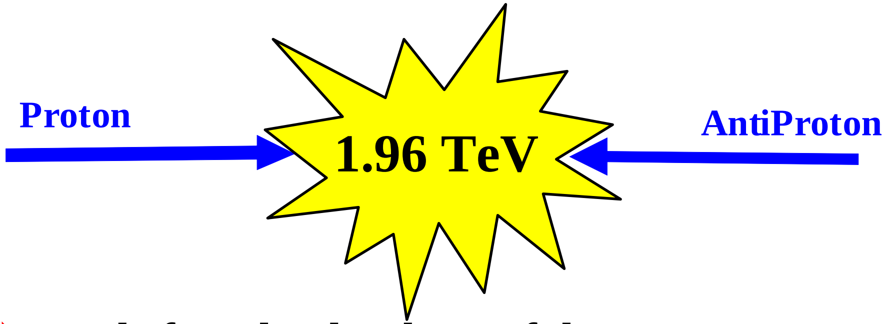


CMS at the LHC
900 GeV, 7 & 8 TeV

Tevatron Energy Scan





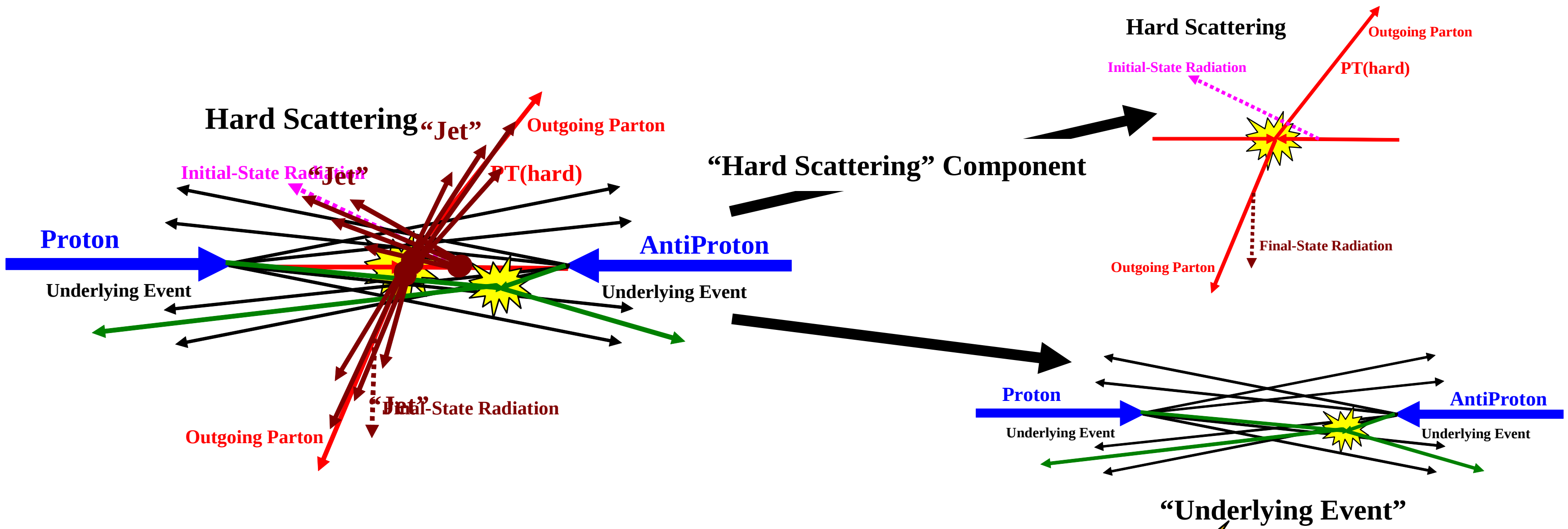


- **Just before the shutdown of the Tevatron CDF has collected more than 10M "min-bias" events at several center-of-mass energies!**

300 GeV 12.1M MB Events

900 GeV 54.3M MB Events

QCD Monte-Carlo Models: High Transverse Momentum Jets

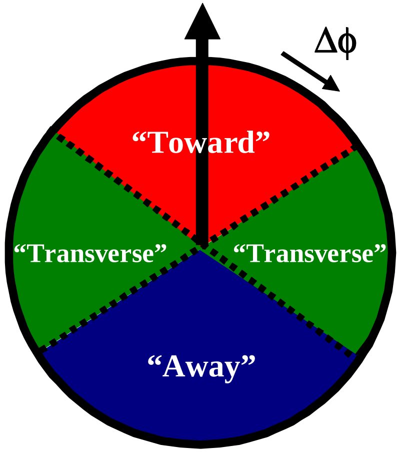


- **Start with the perturbative 2-to-2 (or sometimes 2-to-3) parton-parton scatter g and add initial and final-state gluon radiation (in the leading log approximation or modified leadin g approximation).**
- **The "underlying event" consists of the "beam-beam remnants" and articles arising from soft or semi-soft multiple parton interactions (MPI).**
- **Of course the outgoing colored parton bly "underlying event" observables receive contributions fron**

The "underlying event" is an unavoidable background to most collider observables and having good understand of it leads to more precise collider measurements!

Jet Observables

- **"Toward" Charged Particle Density:** Number of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the "toward" region (not including PTmax) as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut}\times2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.
- **"Toward" Charged PTsum Density:** Scalar p_T sum of the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the "toward" region (not including PTmax) as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut}\times2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

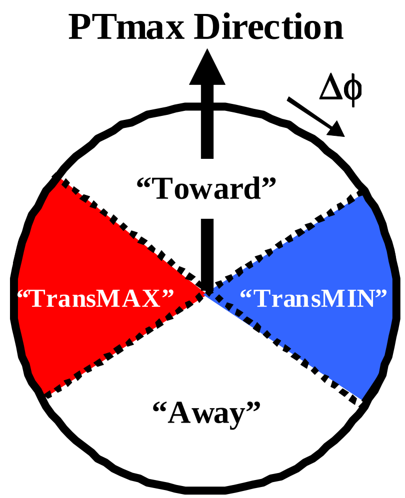


- **"Away" Charged Particle Density:** Number of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the "away" region as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut}\times2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.
- **"Away" Charged PTsum Density:** Scalar p_T sum of the charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the "away" region as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut}\times2\pi/3$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.

$\eta_{cut} = 0.8$

UE Observables

- **"transMAX" and "transMIN" Charged Particle Density:** Number of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the the maximum (minimum) of the two "transverse" regions as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut}\times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.
- **"transMAX" and "transMIN" Charged PTsum Density:** Scalar p_T sum of charged particles ($p_T > 0.5$ GeV/c, $|\eta| < 0.8$) in the the maximum (minimum) of the two "transverse" regions as defined by the leading charged particle, PTmax, divided by the area in η-ϕ space, $2\eta_{cut}\times 2\pi/6$, averaged over all events with at least one particle with $p_T > 0.5$ GeV/c, $|\eta| < \eta_{cut}$.



$\eta_{cut} = 0.8$

Overall "Transverse" = "transMAX" + "transMIN"

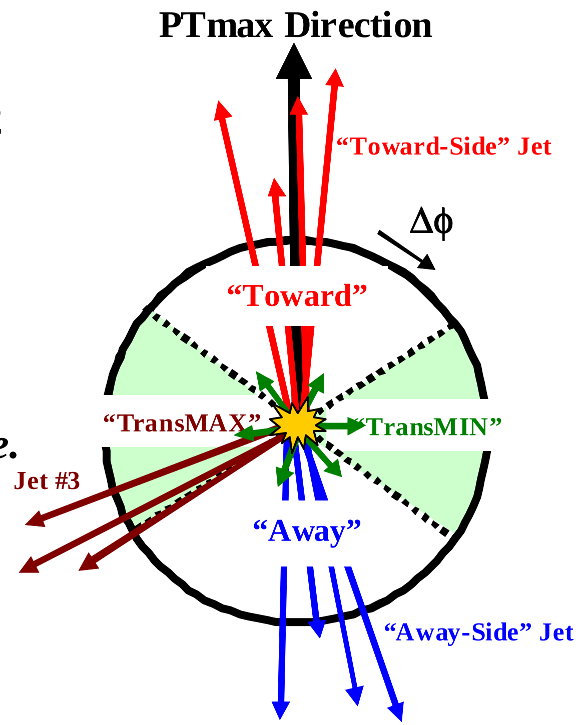
Note: The overall "transverse" density is equal to the average of the "transMAX" and "TransMIN" densities. The "TransDIF" Density is the "transMAX" Density minus the "transMIN" Density

"Transverse" Density = "transAVE" Density = ("transMAX" Density + "transMIN" Density)/2

"TransDIF" Density = "transMAX" Density - "transMIN" Density

"transMIN" & "transDIF"

- The "toward" region contains the leading "jet", while the "away" region, on the average, contains the "away-side" "jet". The "transverse" region is perpendicular to the plane of the hard 2-to-2 scattering and is very sensitive to the "underlying event". For events with large initial or final-state radiation the "transMAX" region defined contains the third jet while both the "transMAX" and "transMIN" regions receive contributions from the MPI and beam-beam remnants. Thus, the "transMIN" region is very sensitive to the multiple parton interactions (MPI) and beam-beam remnants (BBR), while the "transMAX" minus the "transMIN" (*i.e.* "transDIF") is very sensitive to initial-state radiation (ISR) and final-state radiation (FSR).



"TransMIN" density more sensitive to MPI & BBR.

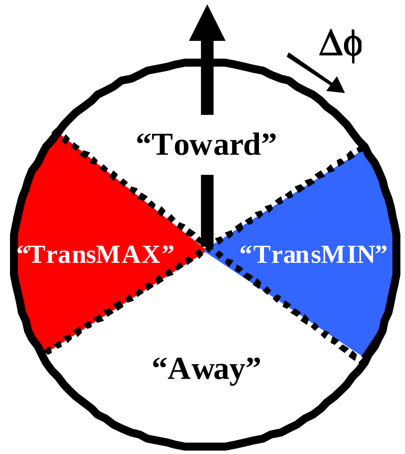
"TransDIF" density more sensitive to ISR & FSR.

0 ≤ "TransDIF" ≤ 2×"TransAVE"

"TransDIF" = "TransAVE" if "TransMIX" = 3×"TransMIN"

PTmax UE Data

- **CDF PTmax UE Analysis: "Towards", "Away", "transMAX", "transMIN", "transAVE", and "transDIF" charged particle and PTsum densities (p_T > 0.5 GeV/c, $|\eta|$ < 0.8) in proton-antiproton collisions at 300 GeV, 900 GeV, and 1.96 TeV (R. Field analysis).**

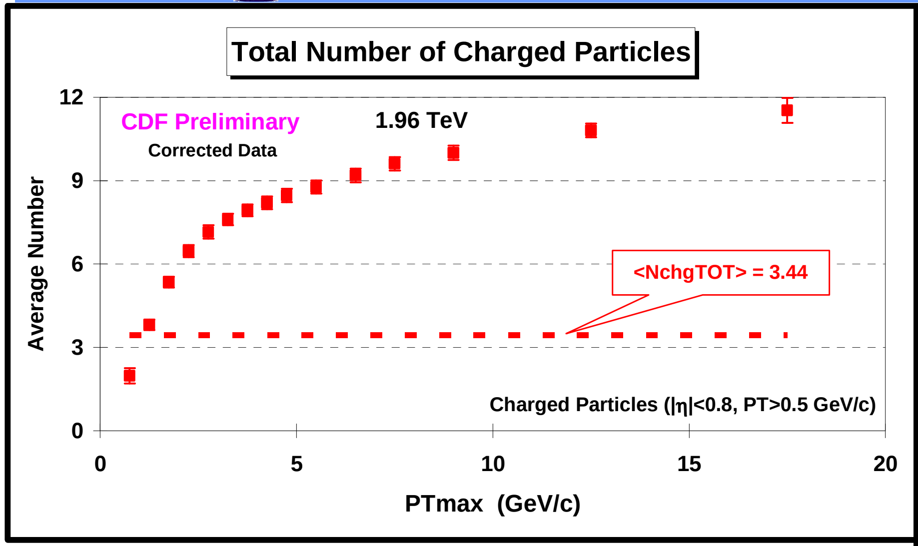


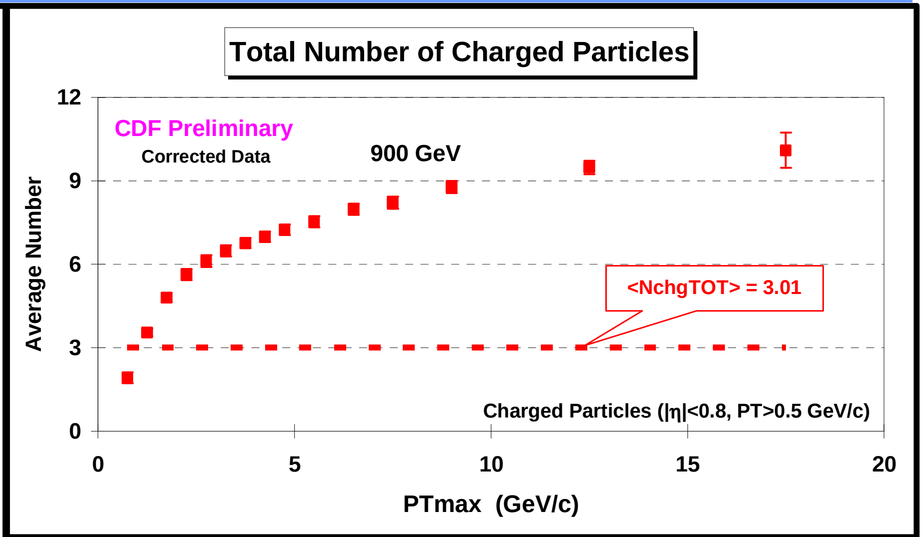
- **CMS PTmax UE Analysis: "Towards", "Away", "transMAX", "transMIN", "transAVE", and "transDIF" charged particle and PTsum densities (p_T > 0.5 GeV/c, $|\eta|$ < 0.8) in proton-proton collisions at 900 GeV and 7 TeV (Mohammed Zakaria Ph.D. Thesis, CMS PAS FSQ-12-020).**

- **Old CMS UE Tunes: PYTHIA 6.4 Tune Z1 (CTEQ5L) and PYTHIA 6.4 Tune Z2* (CTEQ6L) and PYTHIA 8 Tune 4C* (CTEQ6L). All 3 were tuned to the CMS leading chgjet "transAVE" UE data at 900 GeV and 7 TeV.**

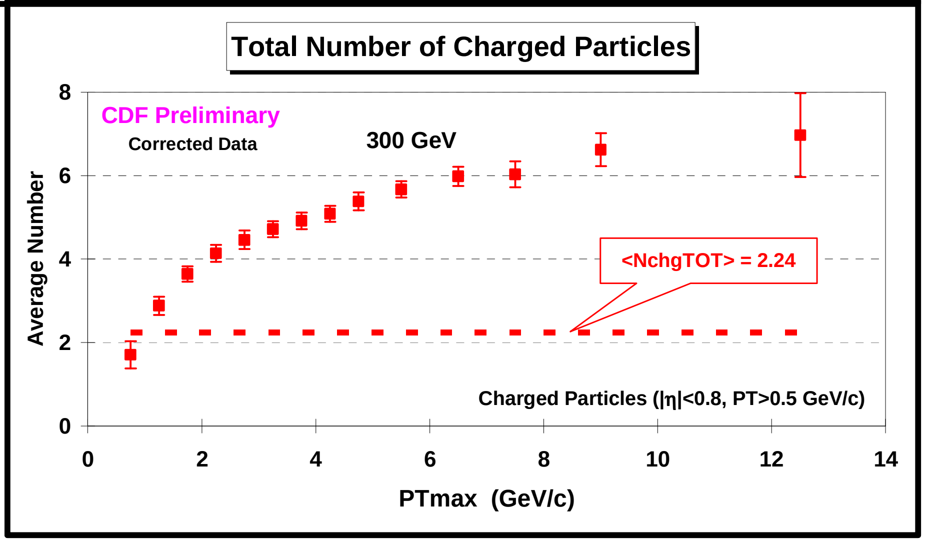
Similar to Tune 4C by Corke and Sjöstrand!

Total Number of Charged Particles

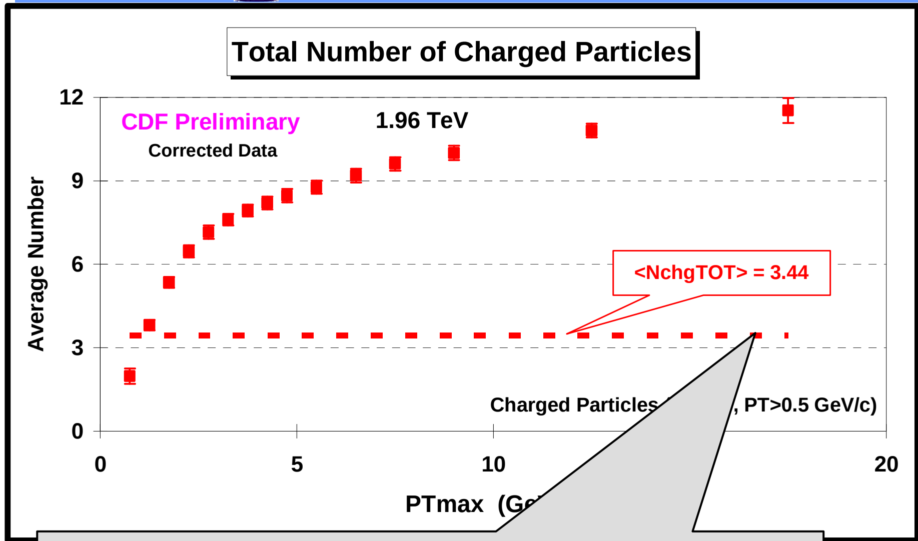


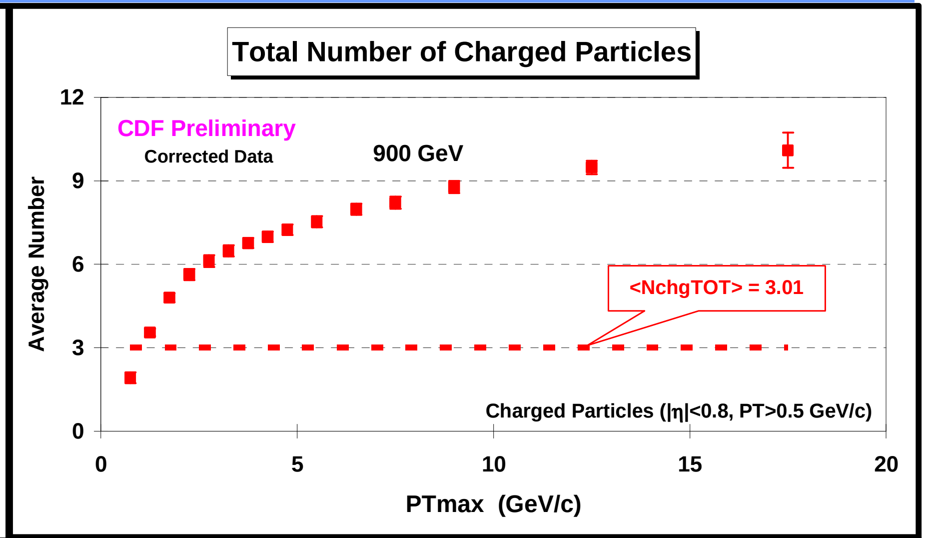


- **CDF data at 1.96 TeV, 900 GeV, and 300 GeV** on the total number of charged particles (including PTmax) as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



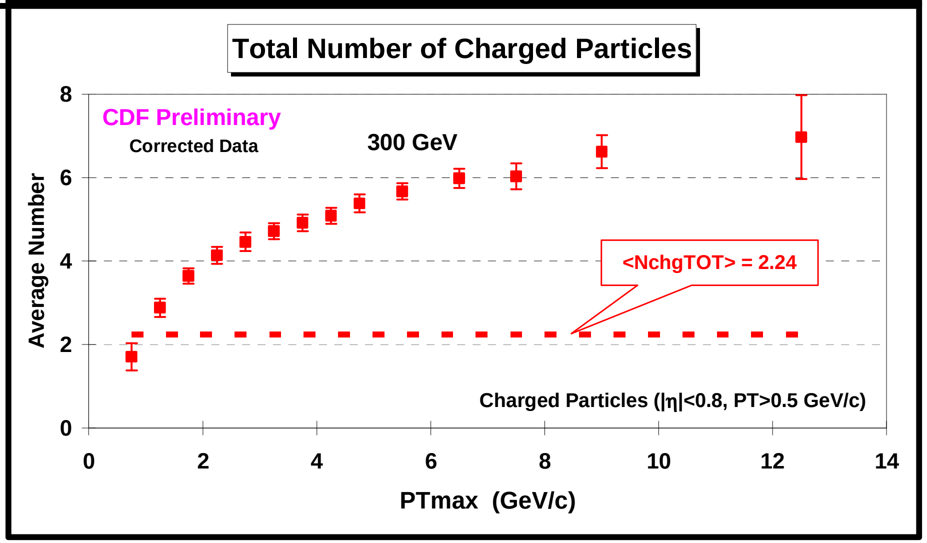
Total Number of Charged Particles



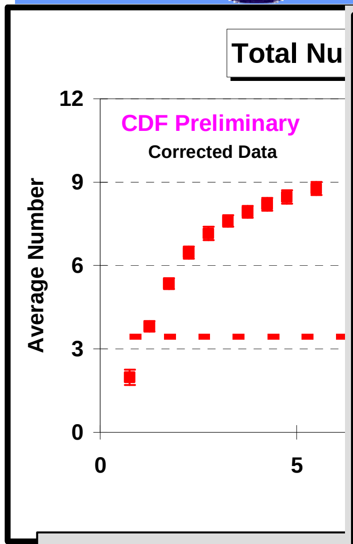


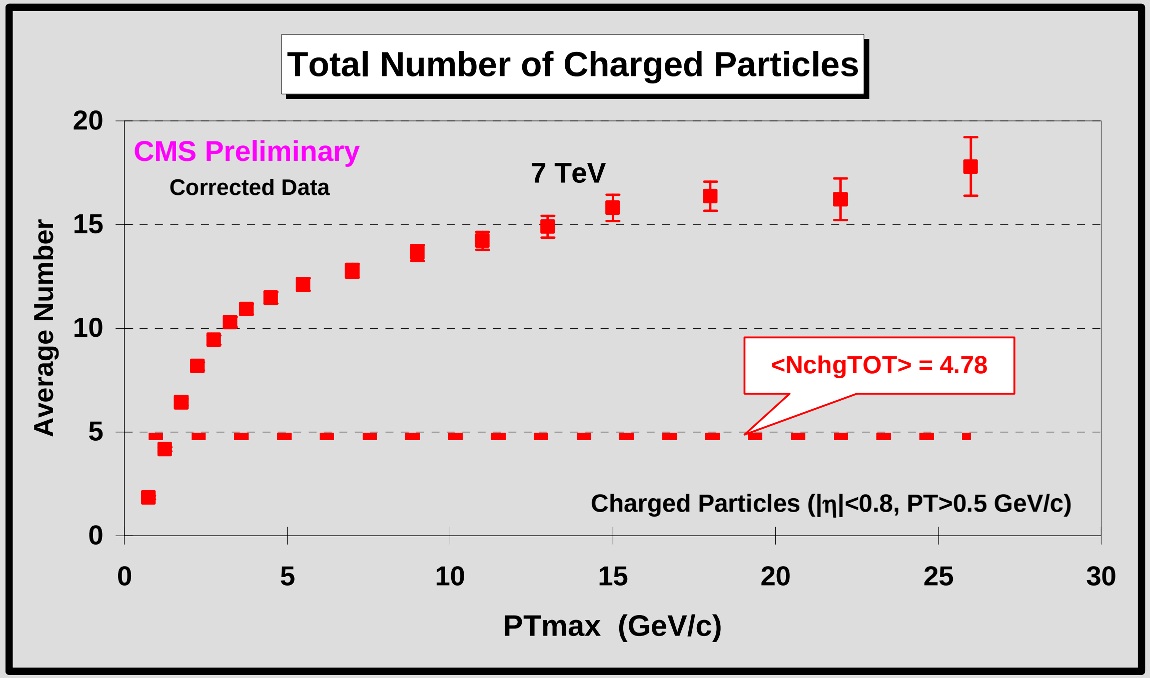
Overall average number of charged particles (including all PTmax values).

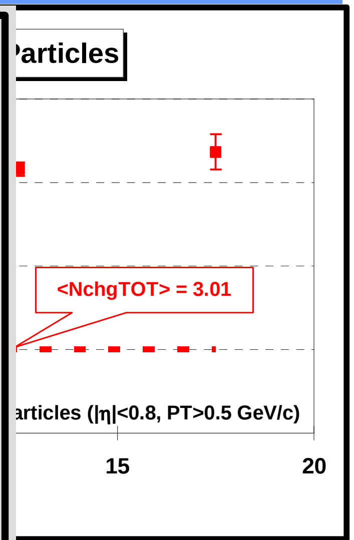
GeV on the total number of charged particles (including PTmax) as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



Total Number of Charged Particles



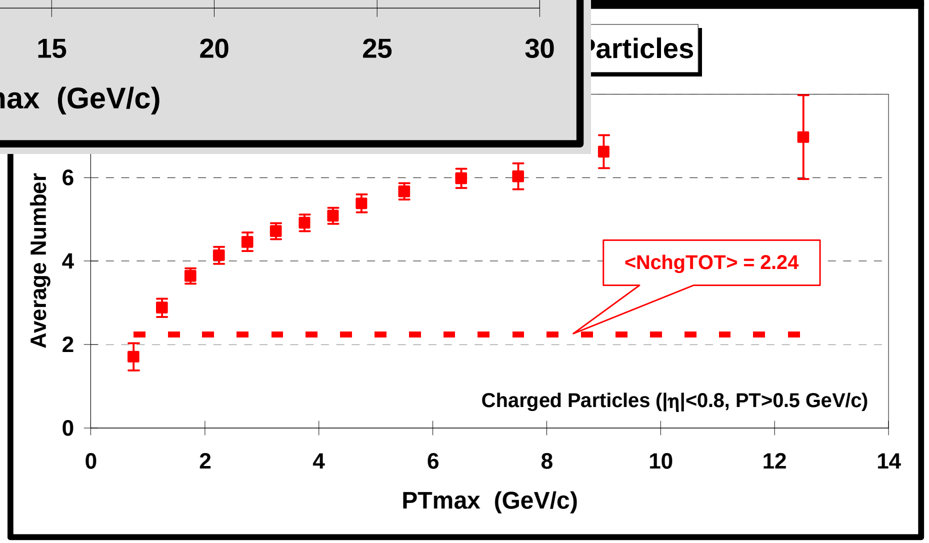




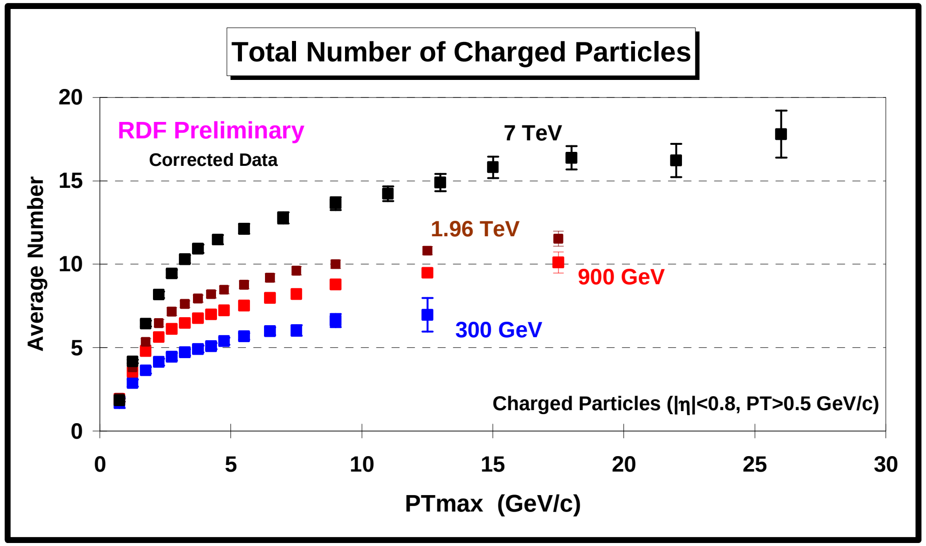
Overall avera
particles (inclu

GeV on the tota

particles (including PTmax) as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

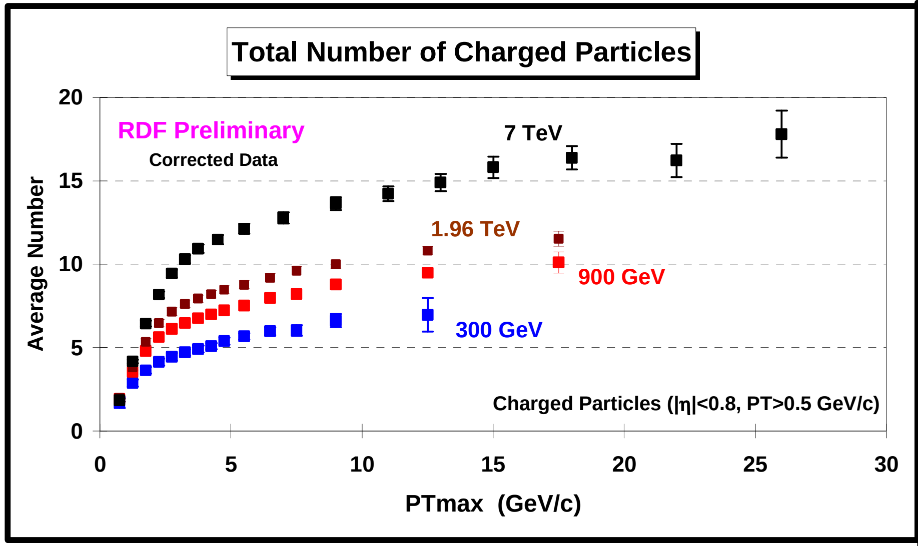


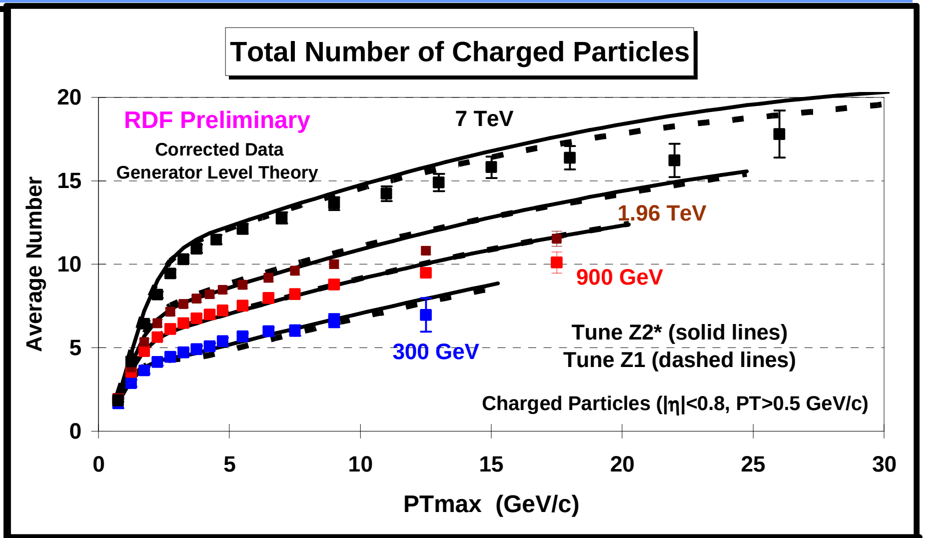
Total Number of Charged Particles

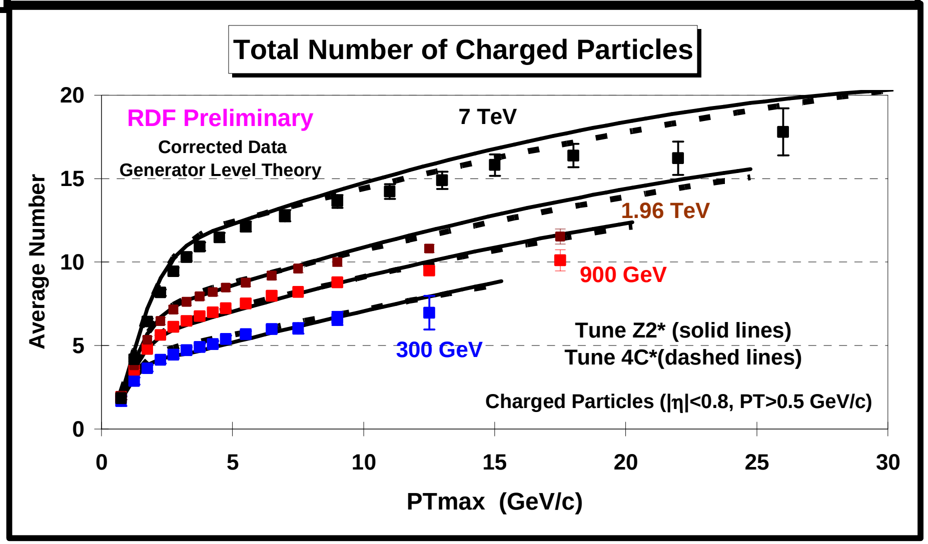


- **CMS and CDF data on the total number of charged particles (including PTmax) as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

Total Number of Charged Particles

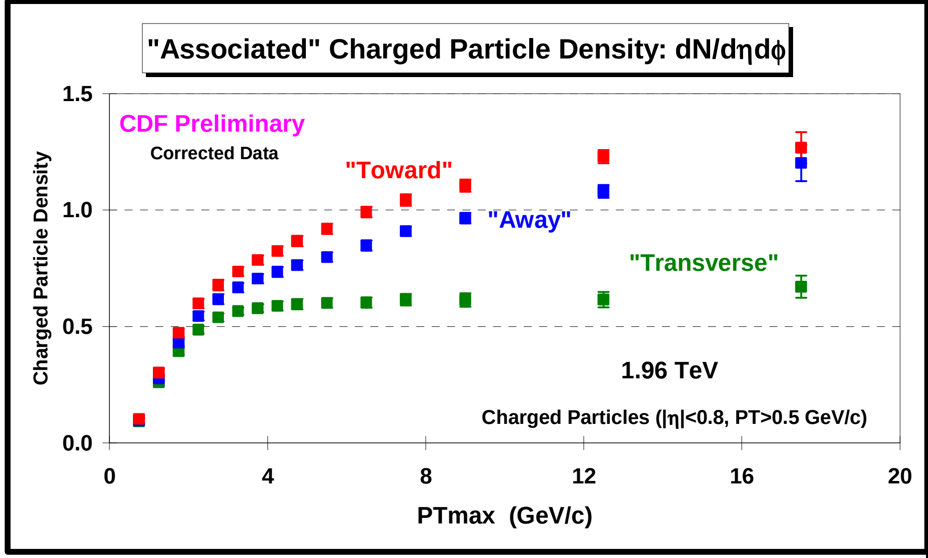


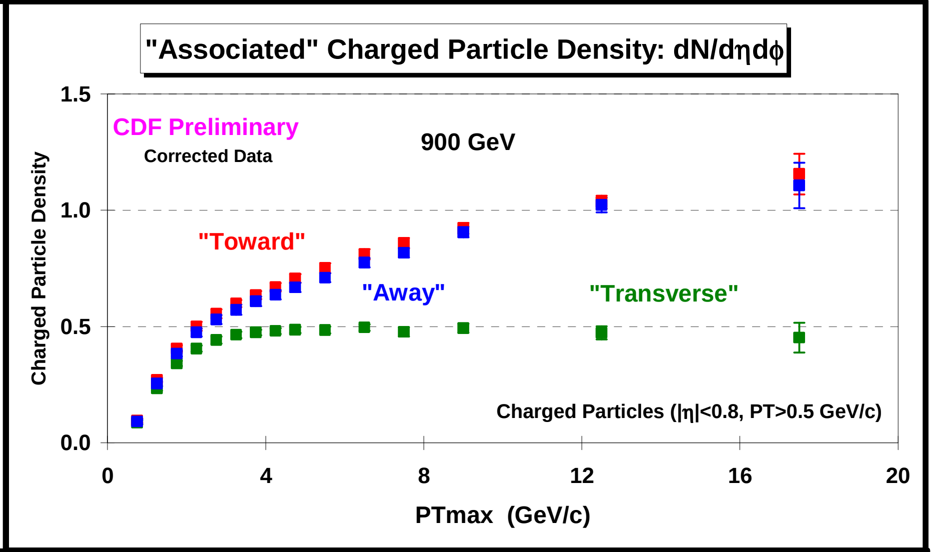




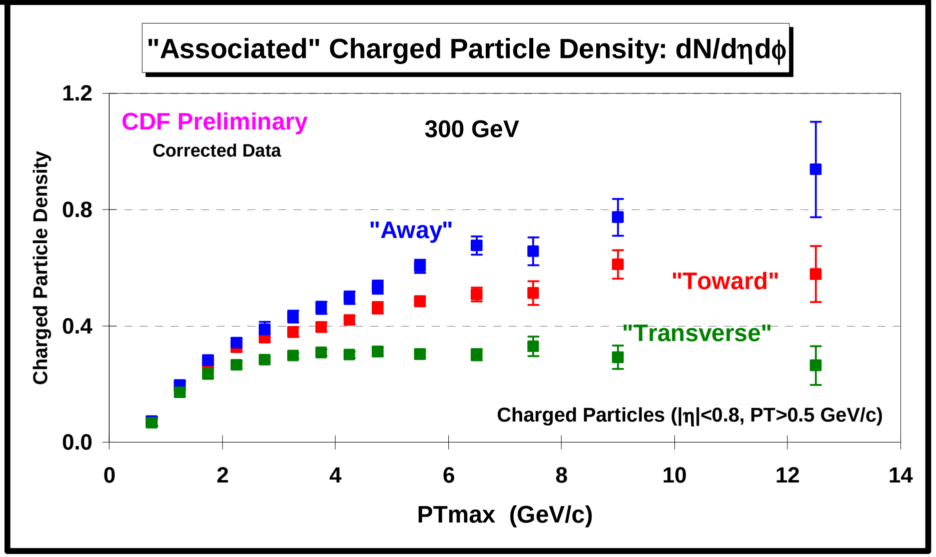
- **CMS and CDF data** on the total number of charged particles (including PTmax) as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

"Associated" Charged Particle Density

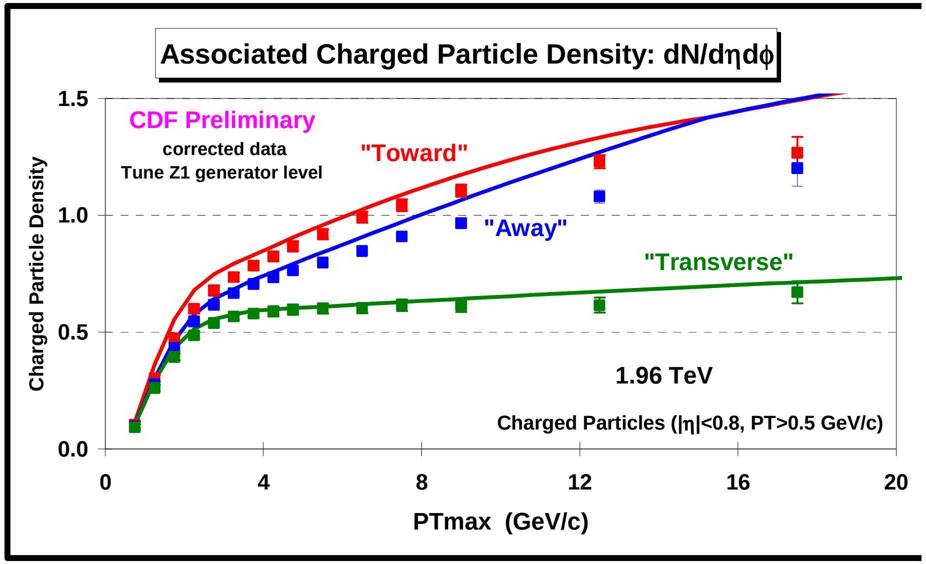


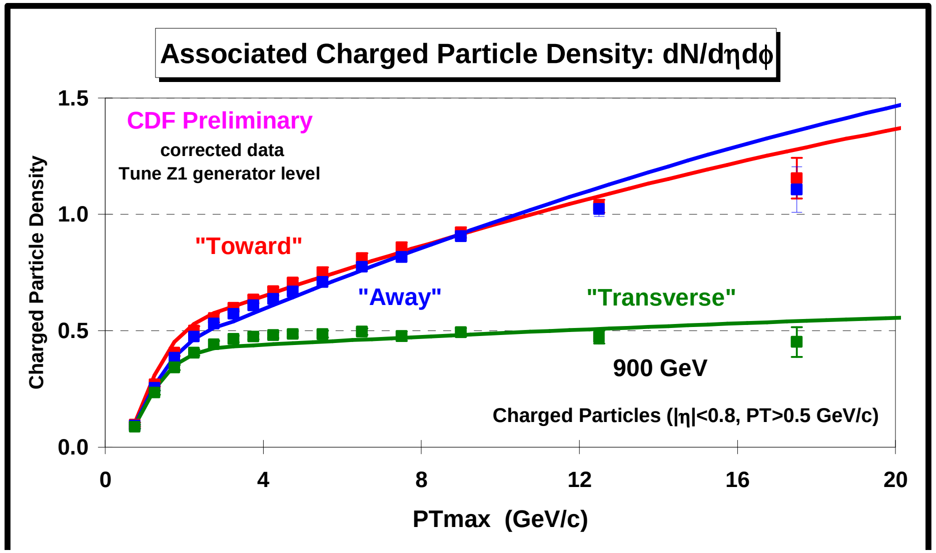


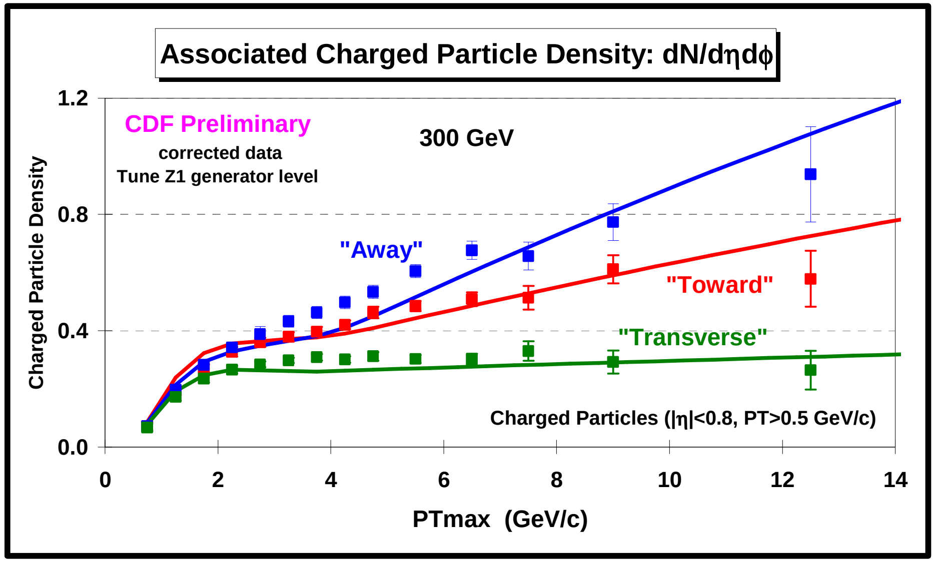
- Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the "associated" charged particle density in the "toward", "away", and "transverse" regions as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



"Associated" Charged Particle Density



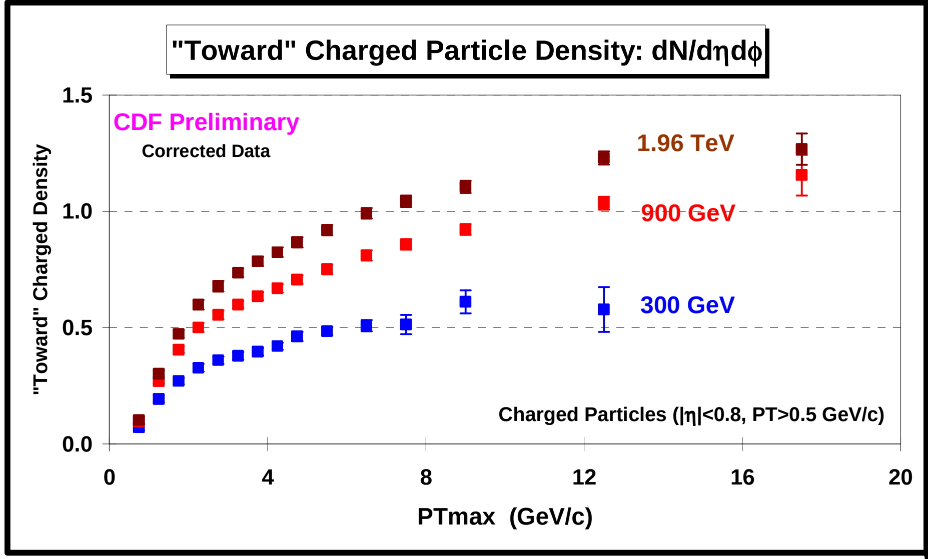


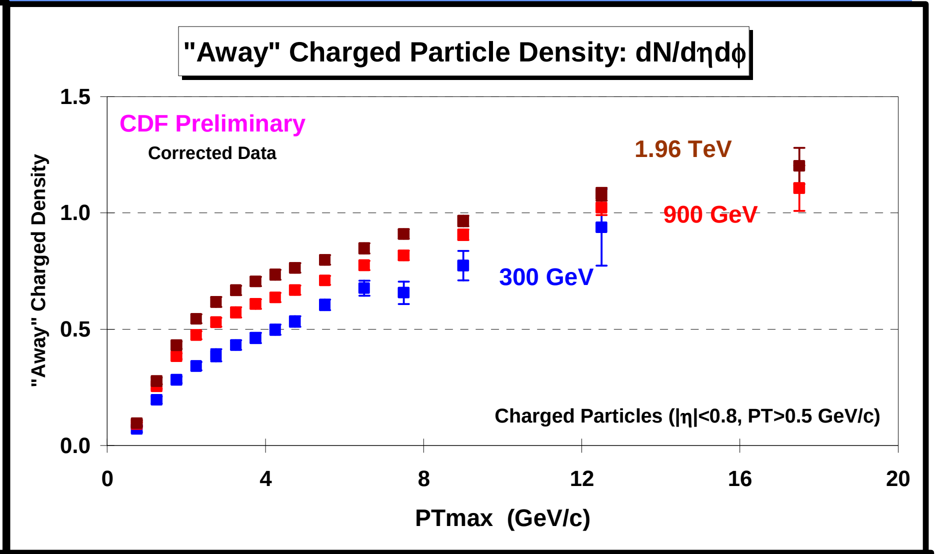


- Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the "associated" charged particle density in the "toward", "away", and "transverse" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

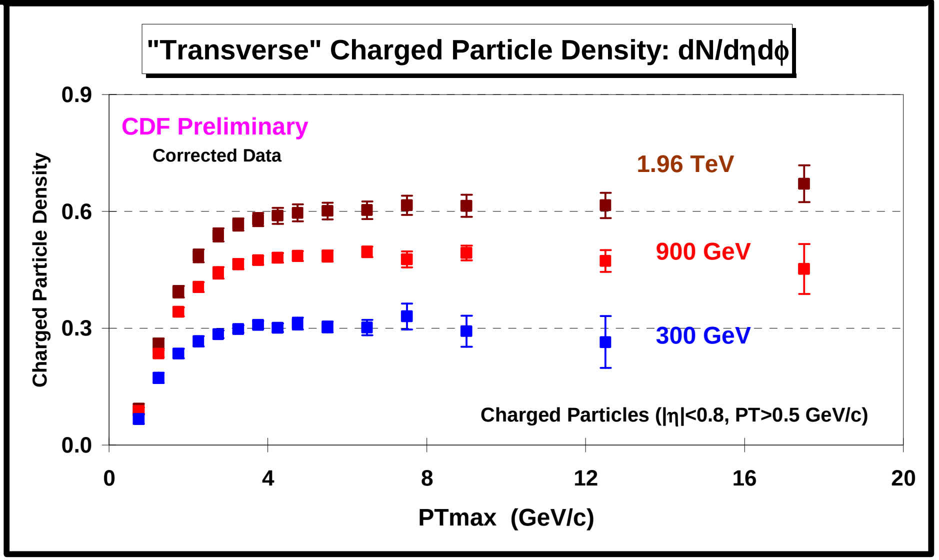
The data are compared with PYTHIA **Tune Z1**.

"Associated" Charged Particle Density

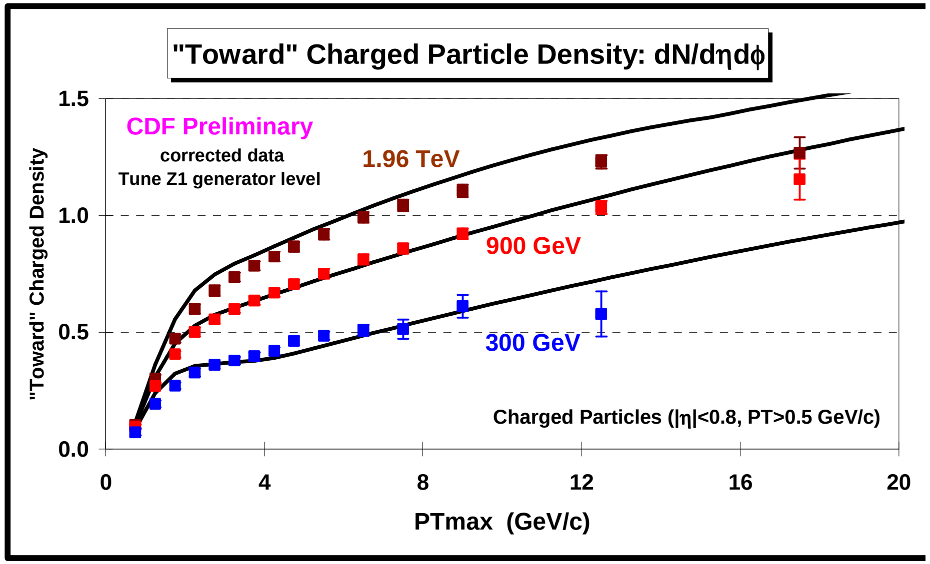


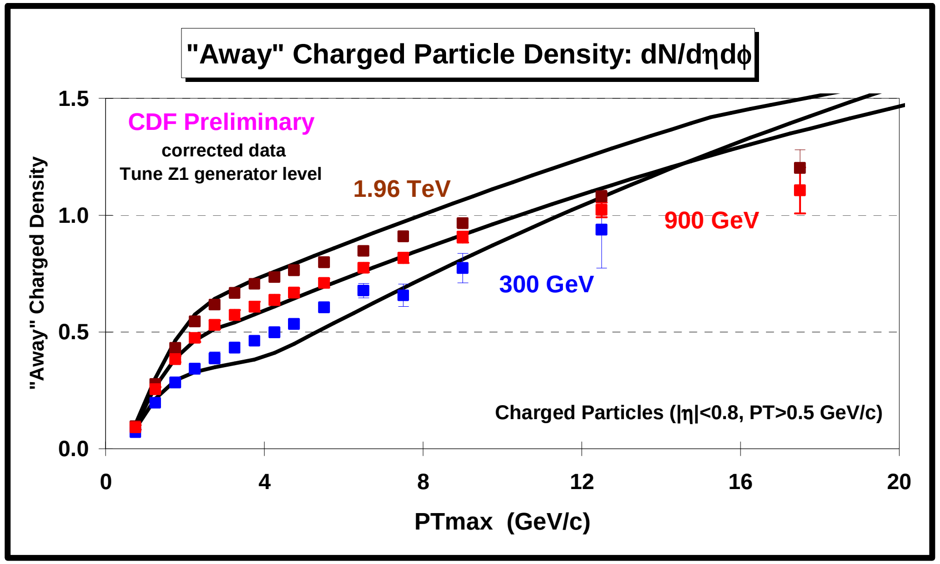


- **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the "associated" charged particle density in the "toward", "away", and "transverse" regions as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**



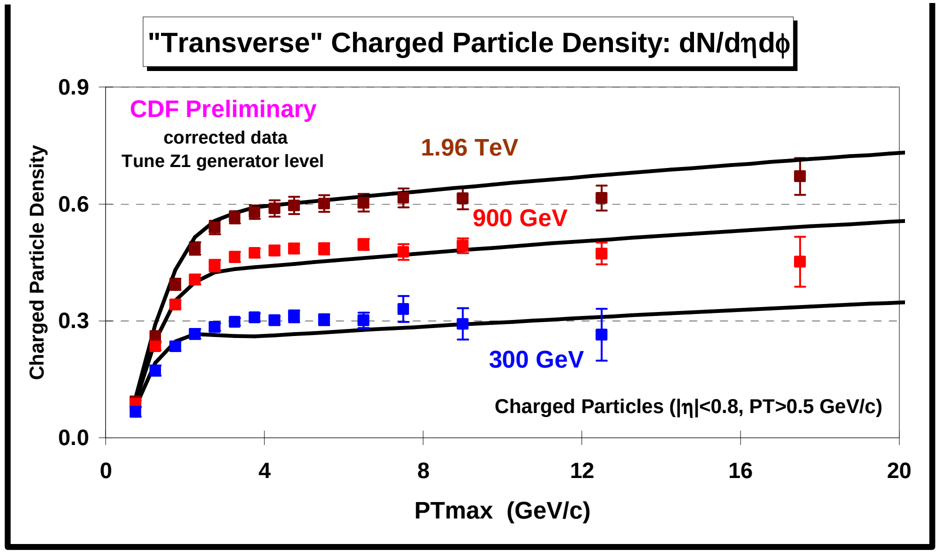
"Associated" Charged Particle Density



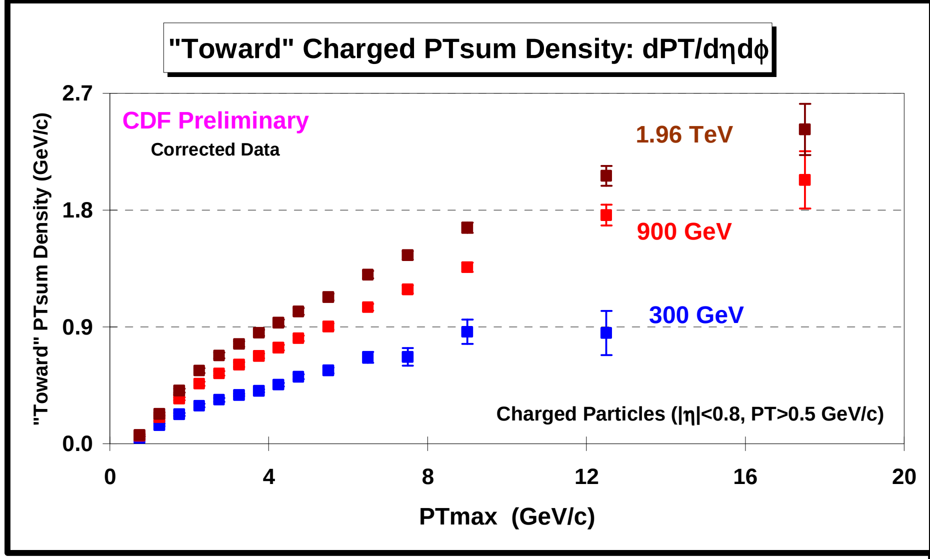


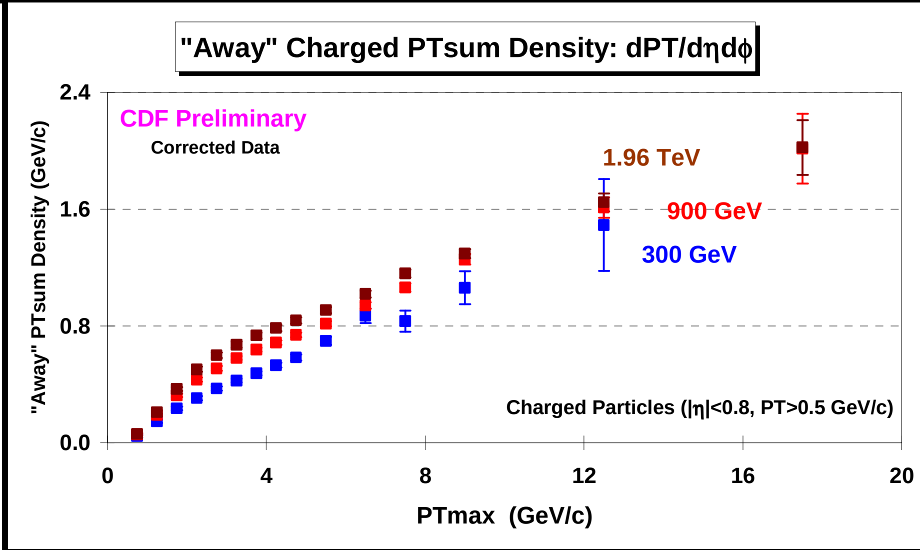
- Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the "associated" charged particle density in the "toward", "away", and "transverse" regions as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

The data are compared with PYTHIA **Tune Z1**.

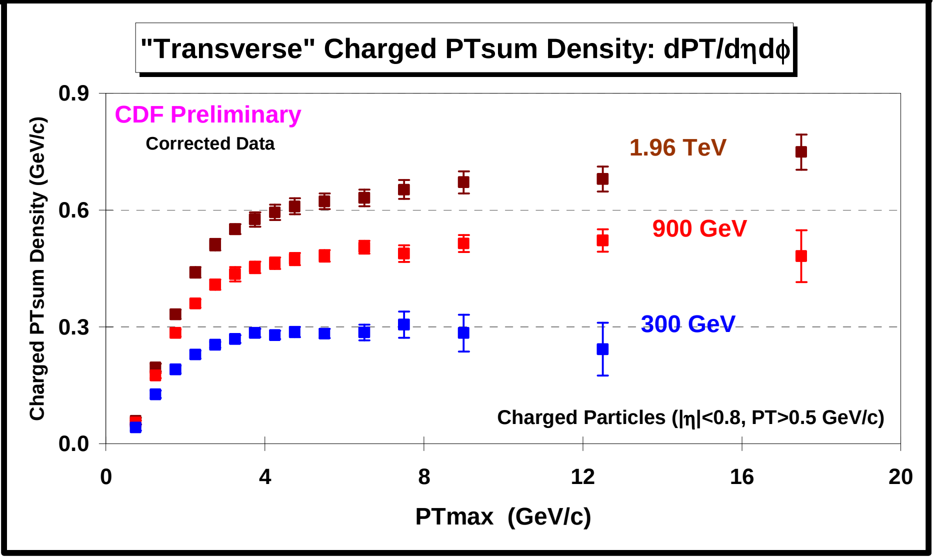


“Associated” Charged PTsum Density

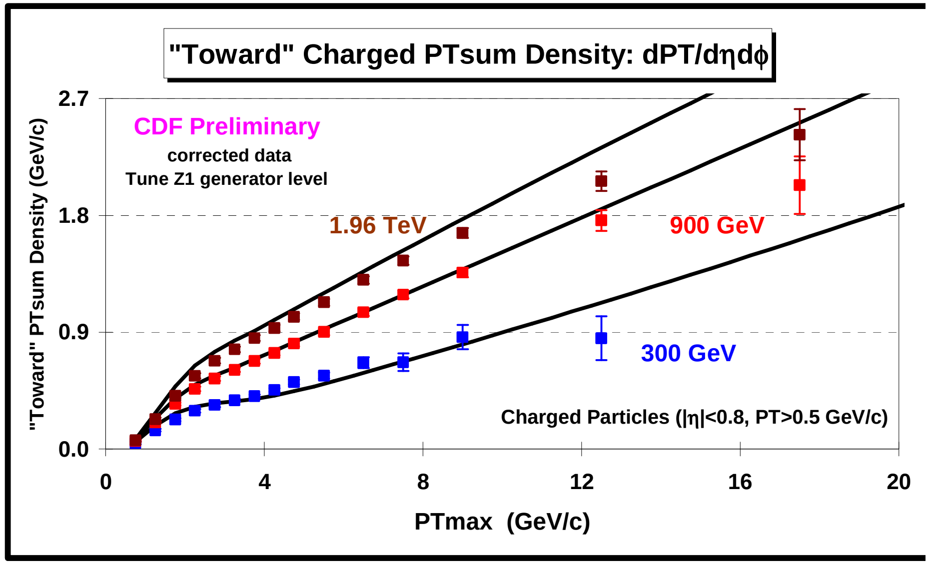


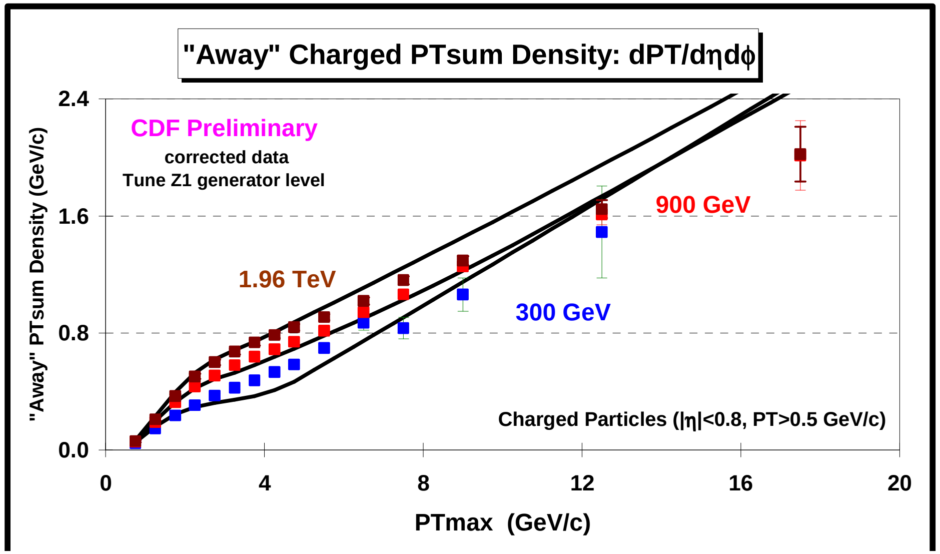


- Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the “associated” charged PTsum density in the “toward”, “away”, and “transverse” regions as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.



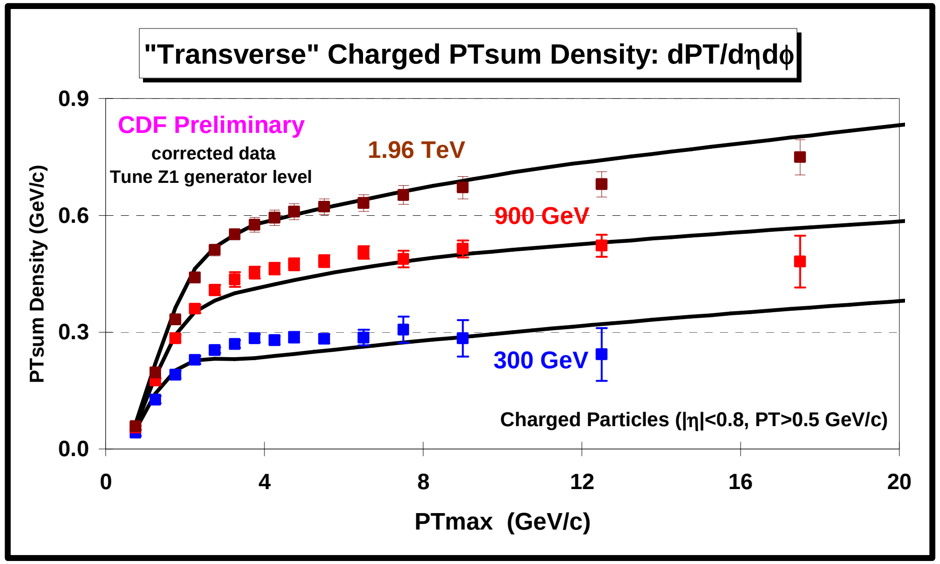
"Associated" Charged PTsum Density



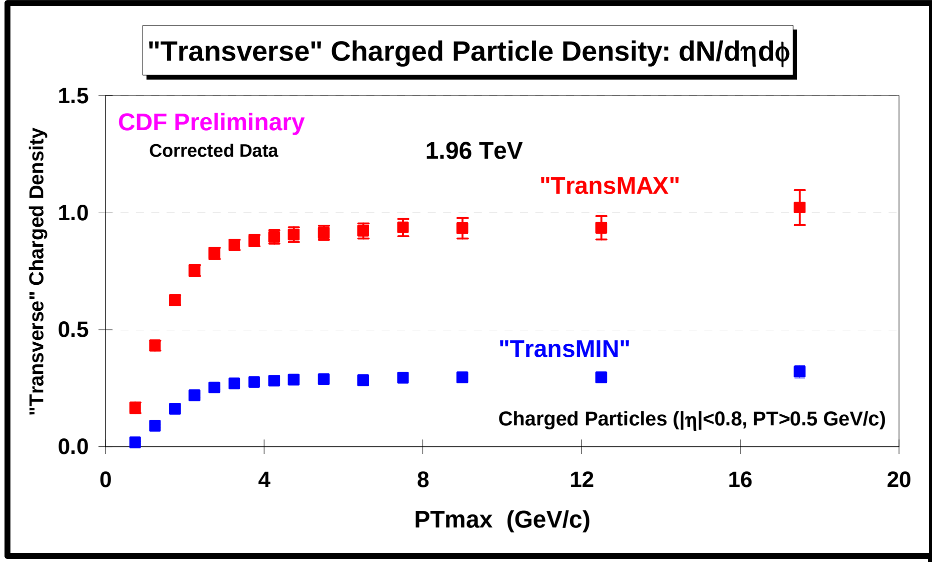


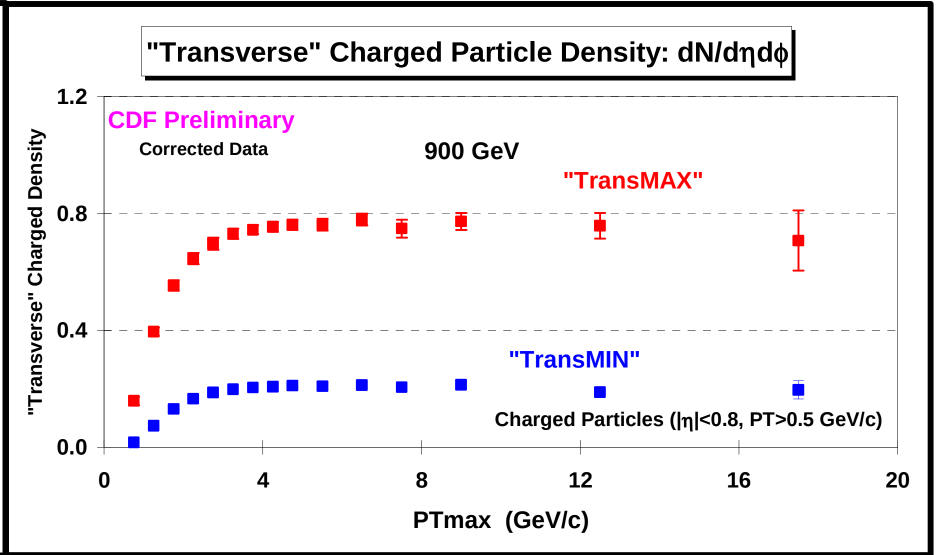
- Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the "associated" charged PTsum density in the "toward", "away", and "transverse" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

The data are compared with PYTHIA **Tune Z1**.

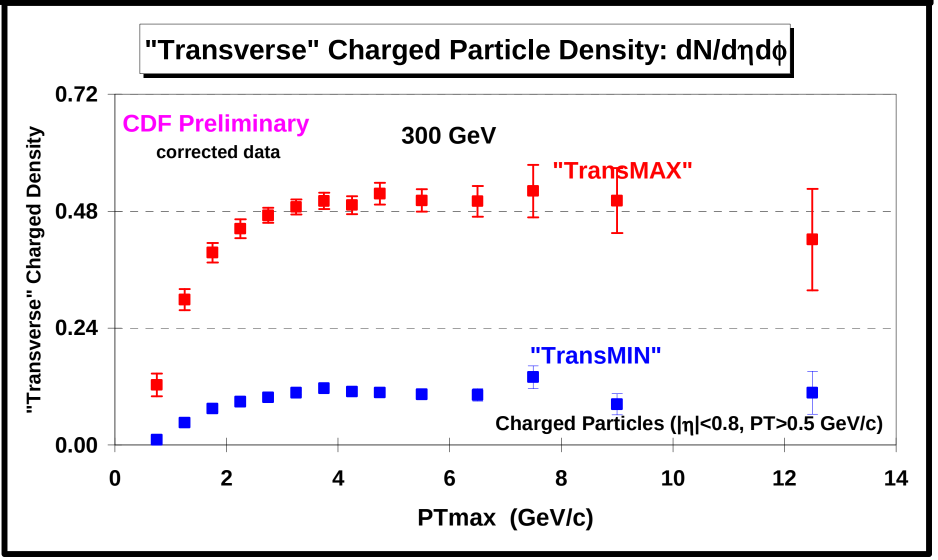


"transMAX/MIN" NchgDen

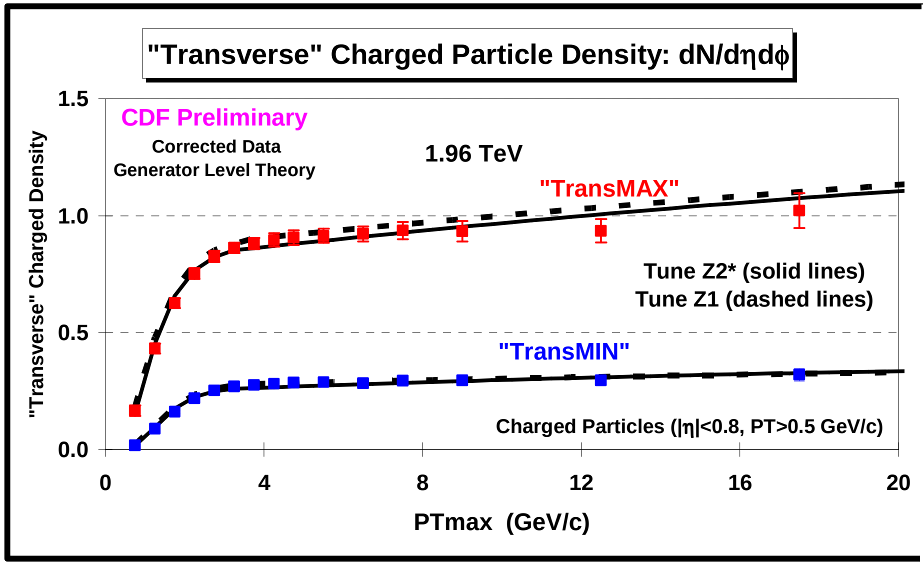


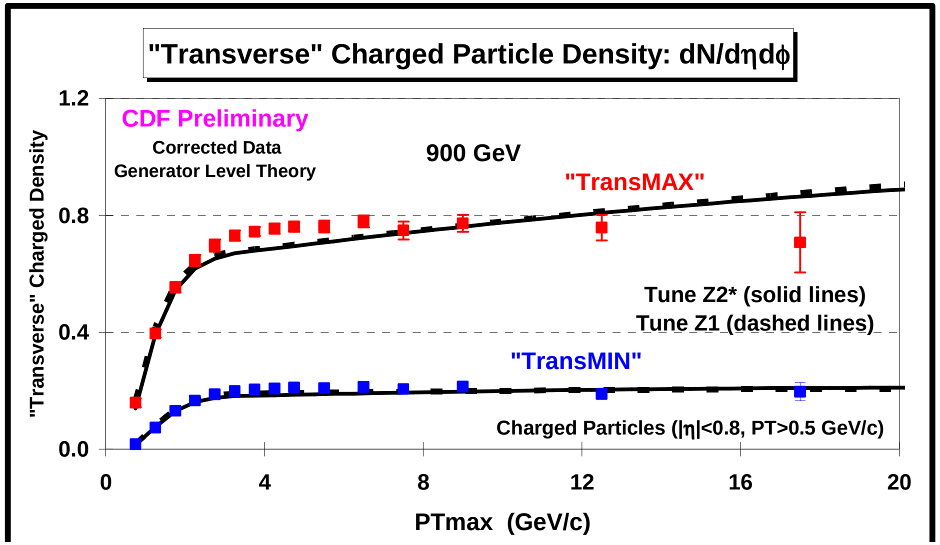


- **Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX" and "transMIN" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**



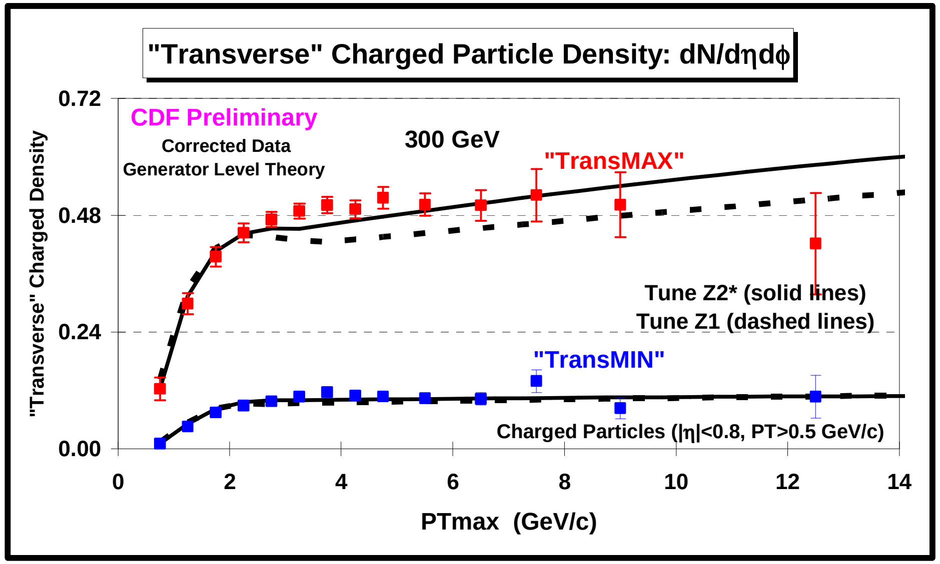
"transMAX/MIN" NchgDen



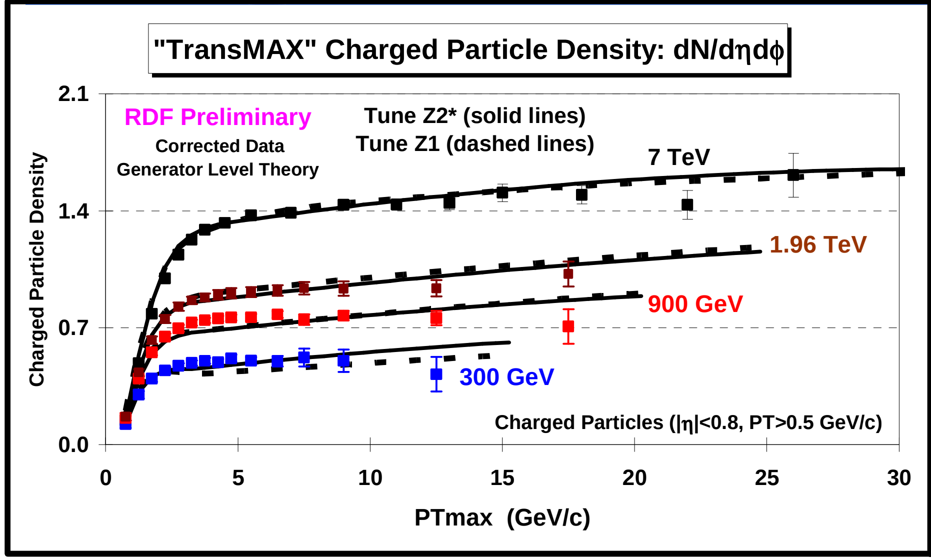


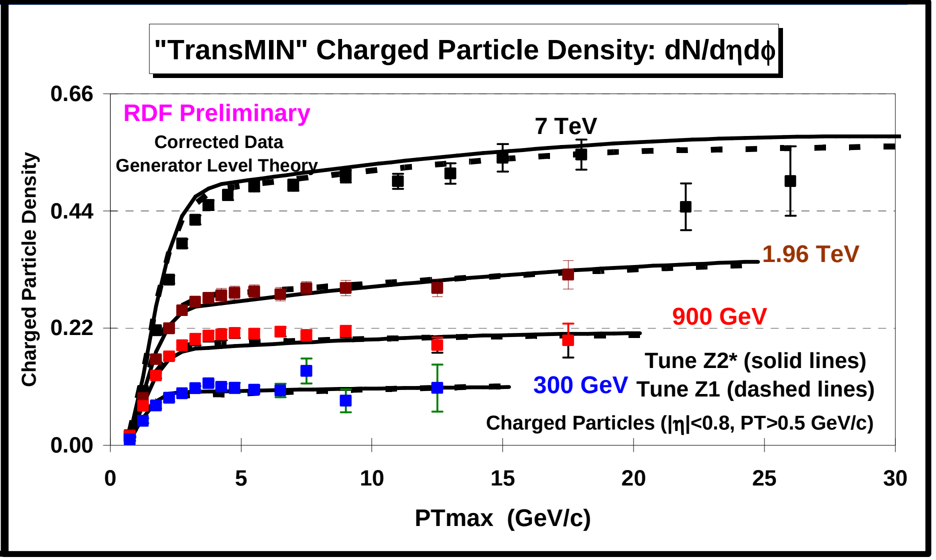
➡ Corrected CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX" and "transMIN" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.

The data are compared with PYTHIA 6.4 Tune Z1 and Tune Z2*.



“transMAX/MIN” NchgDen

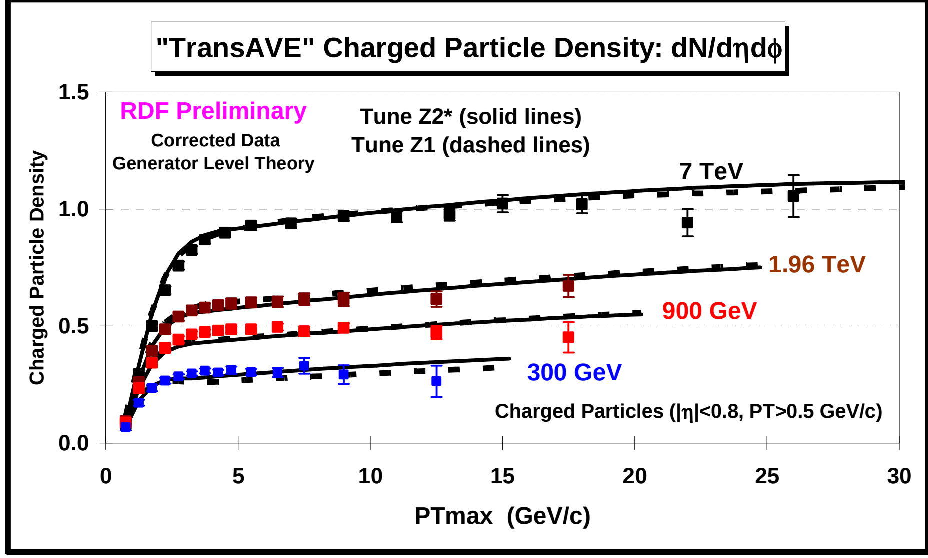


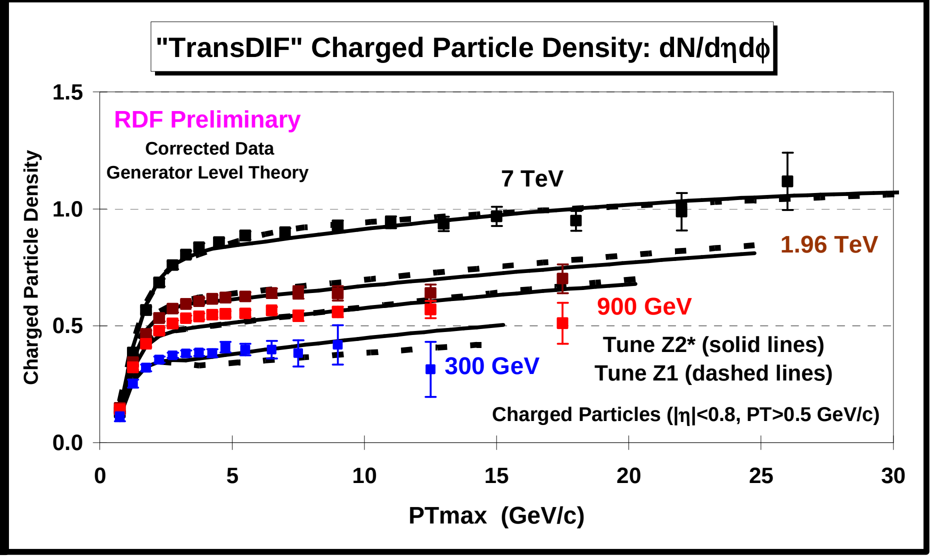


- Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transMAX” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA Tune Z1 and Tune Z2*.

- Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transMIN” region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA Tune Z1 and Tune Z2*.

“transDIF/AVE” NchgDen

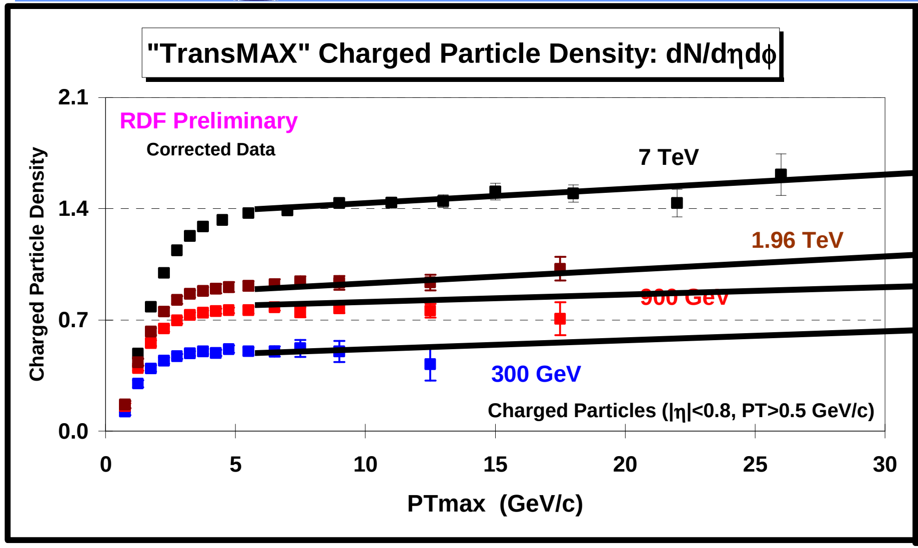


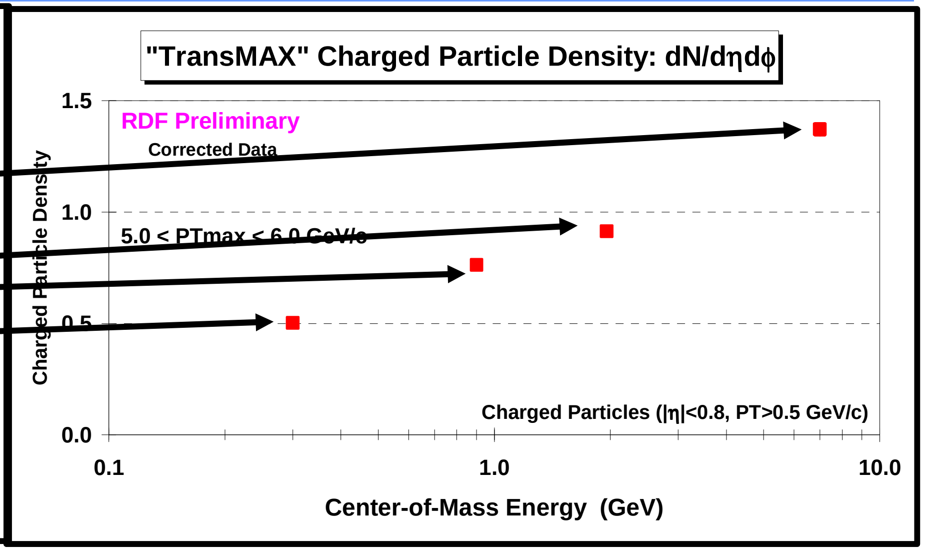


- **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transAVE” region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA Tune Z1 and Tune Z2*.**

- **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transDIF” region as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty. The data are compared with PYTHIA Tune Z1 and Tune Z2*.**

"transMAX" NchgDen vs E_{cm}

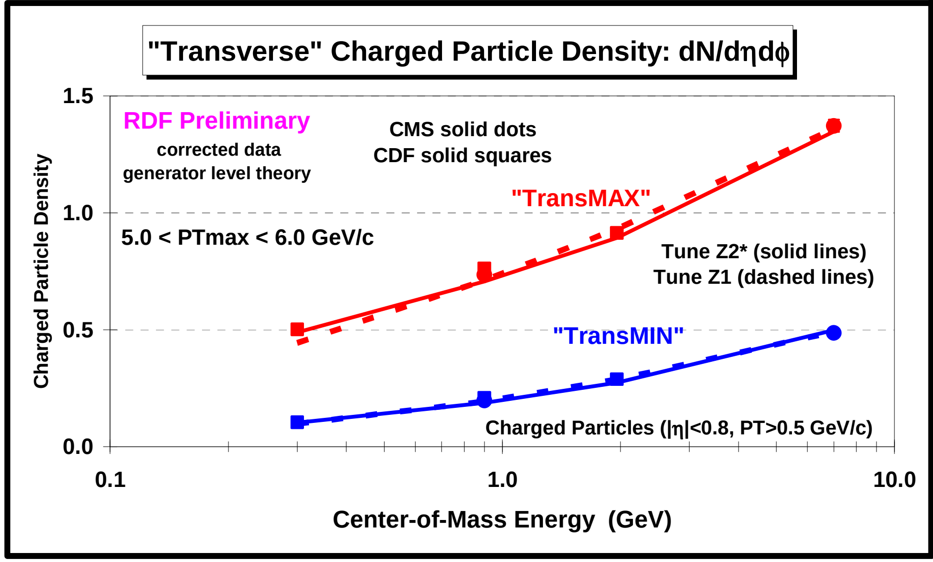


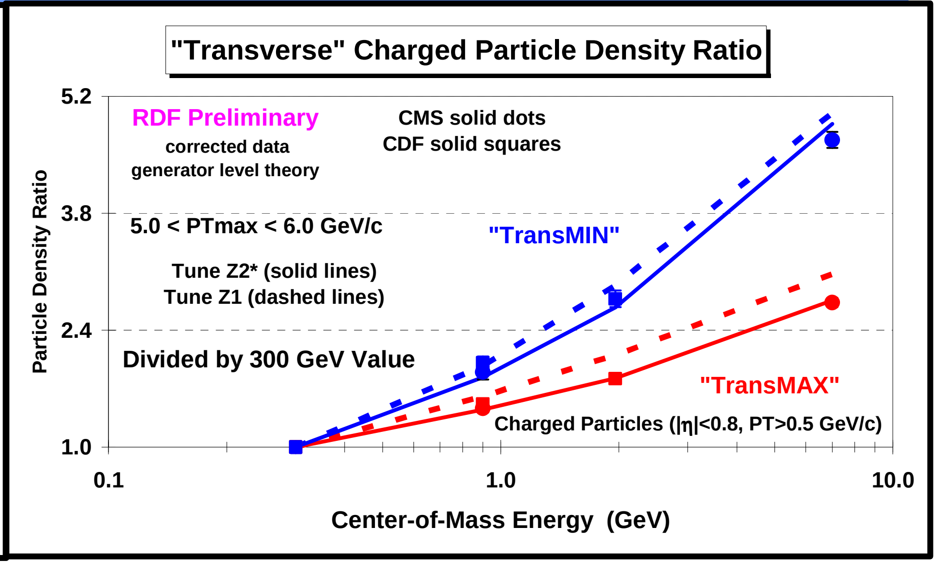


- **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$. The data are corrected to the particle level with errors that include both the statistical error and the systematic uncertainty.**

- **Corrected CMS and CDF data on the charged particle density in the "transMAX" region as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

“Transverse” NchgDen vs E_{cm}



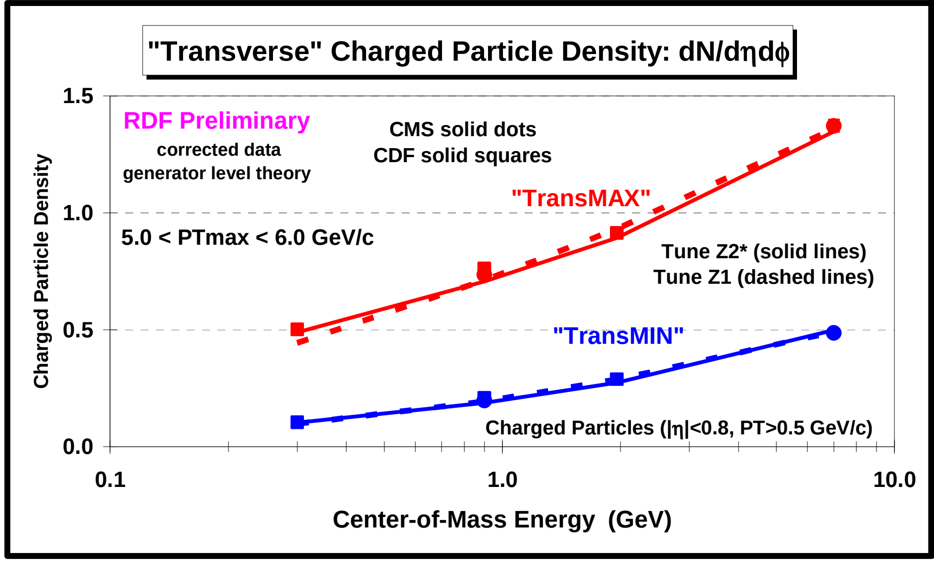


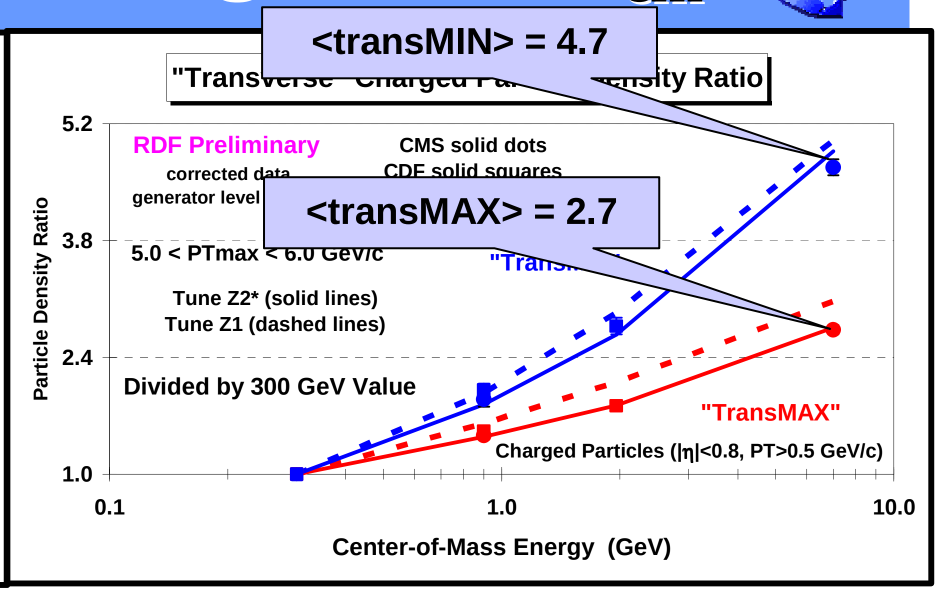
- **Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the “transMAX” and “transMIN” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

- **Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle density in the “transMAX” and “transMIN” regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

The data are compared with PYTHIA Tune Z1 and Tune Z2*.

"Transverse" NchgDen vs E_{cm}



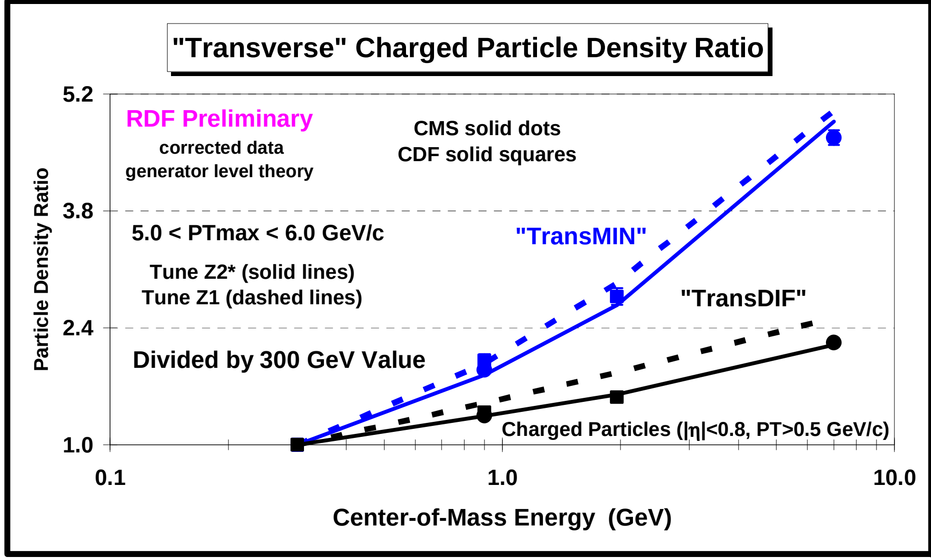


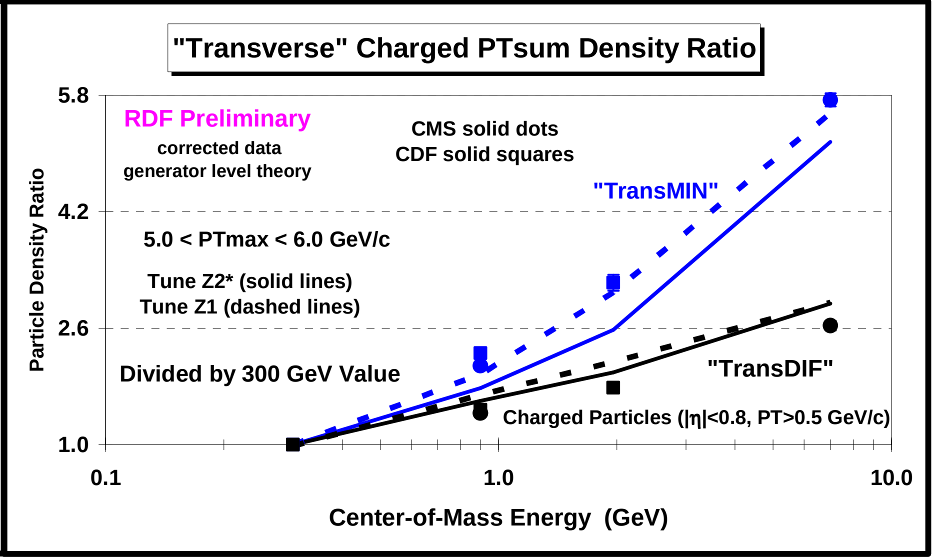
- Corrected CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV on the charged particle density in the "transMAX" and "transMIN" regions as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8 with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).

- Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle density in the "transMAX" and "transMIN" regions as defined by the leading charged particle (PTmax) for charged particles with p_T > 0.5 GeV/c and |η| < 0.8 with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).

The data are compared with PYTHIA Tune Z1 and Tune Z2*.

"TransMIN/DIF" vs E_{cm}



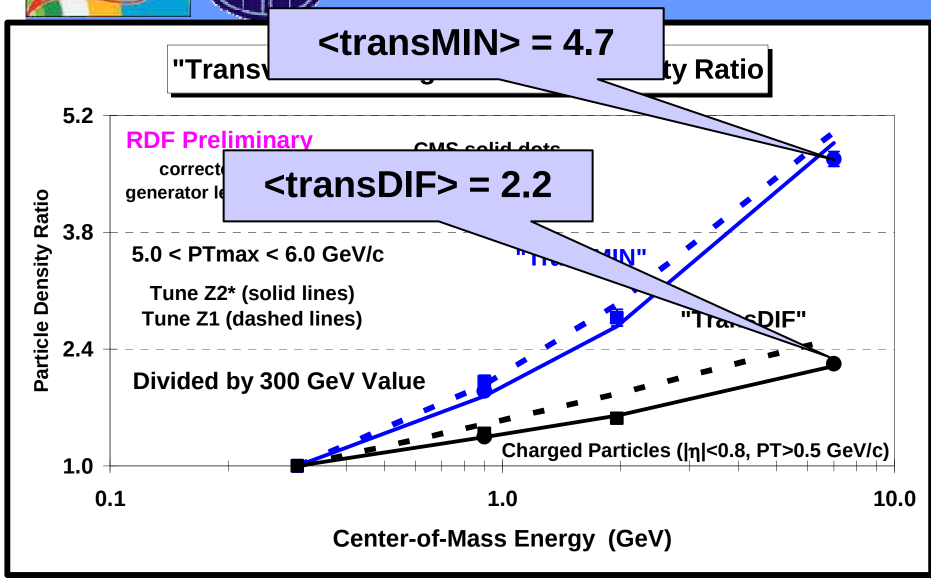


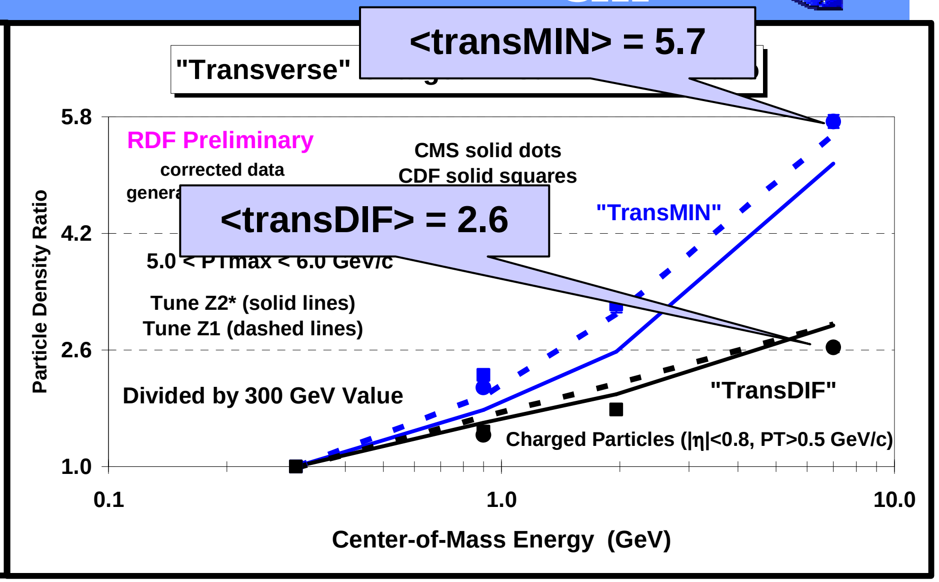
- **Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle density in the "transMIN", and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

- **Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged PTsum density in the "transMIN", and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with 5 < PTmax < 6 GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

The data are compared with PYTHIA Tune Z1 and Tune Z2*.

"TransMIN/DIF" vs E_{cm}



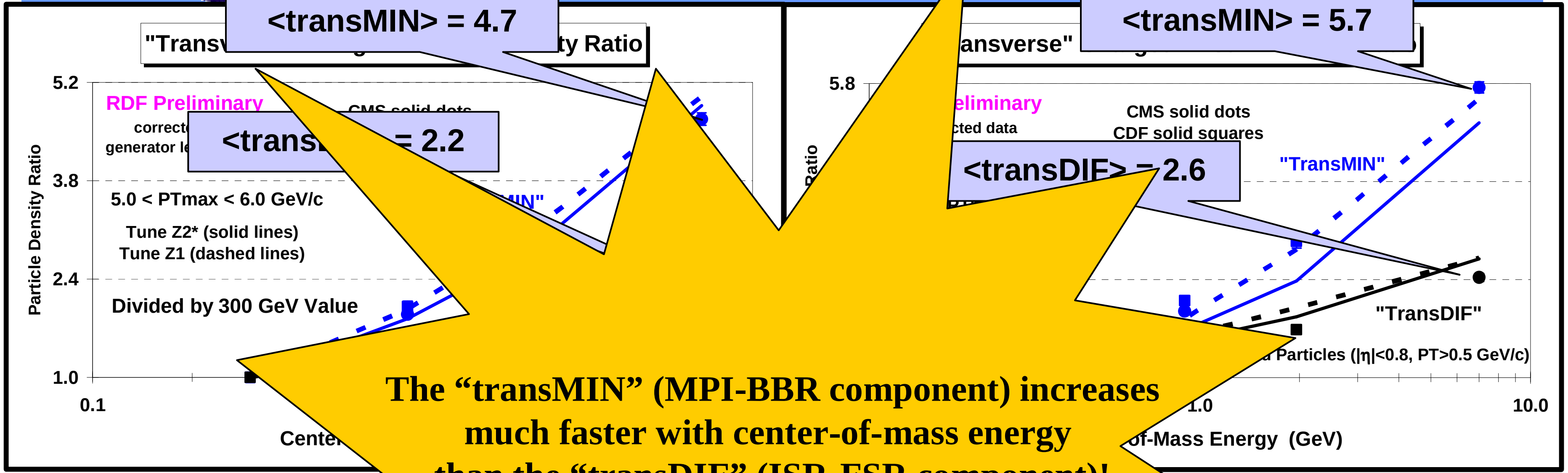


- **Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged particle density in the "transMIN", and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

- **Ratio of CMS data at 7 TeV and CDF data at 1.96 TeV, 900 GeV, and 300 GeV to the value at 300 GeV for the charged PTsum density in the "transMIN", and "transDIF" regions as defined by the leading charged particle (PTmax) for charged particles with $p_T > 0.5$ GeV/c and $|\eta| < 0.8$ with $5 < PTmax < 6$ GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).**

The data are compared with PYTHIA Tune Z1 and Tune Z2*.

"TransMIN/DIF" vs E_{cm}



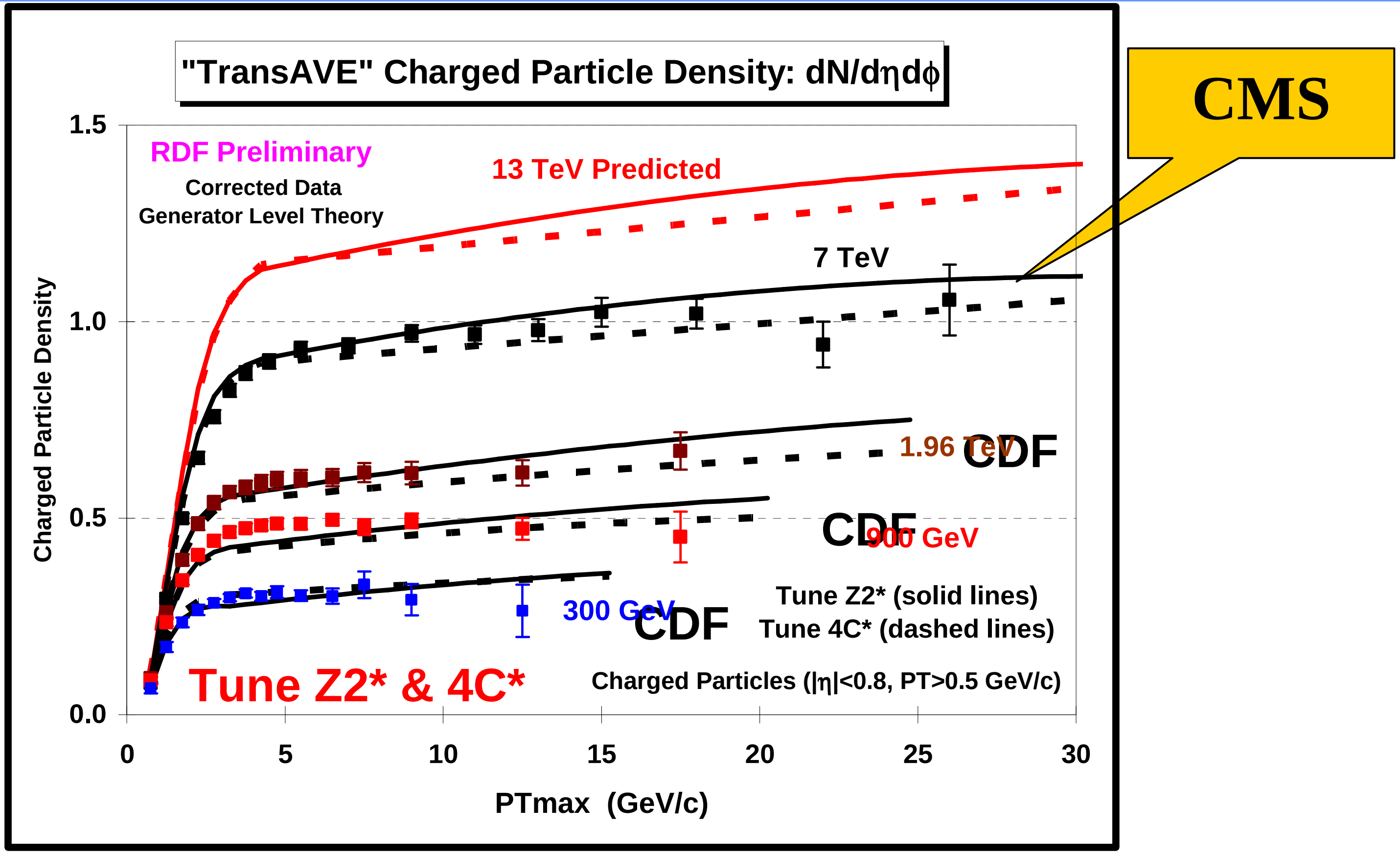
The "transMIN" (MPI-BBR component) increases much faster with center-of-mass energy than the "transDIF" (ISR-FSR component)! Duh!!

- Ratio of CMS data at 7 … 1.96 TeV, 900 GeV, a… at 300 GeV for th… the "transMIN" and "transDI… defined by the leading charge… (PTmax) for charged particle… GeV/c and |η| < 0.8 with 5 < … max < … GeV/c. The data are plotted versus the center-of-mass energy (*log scale*).

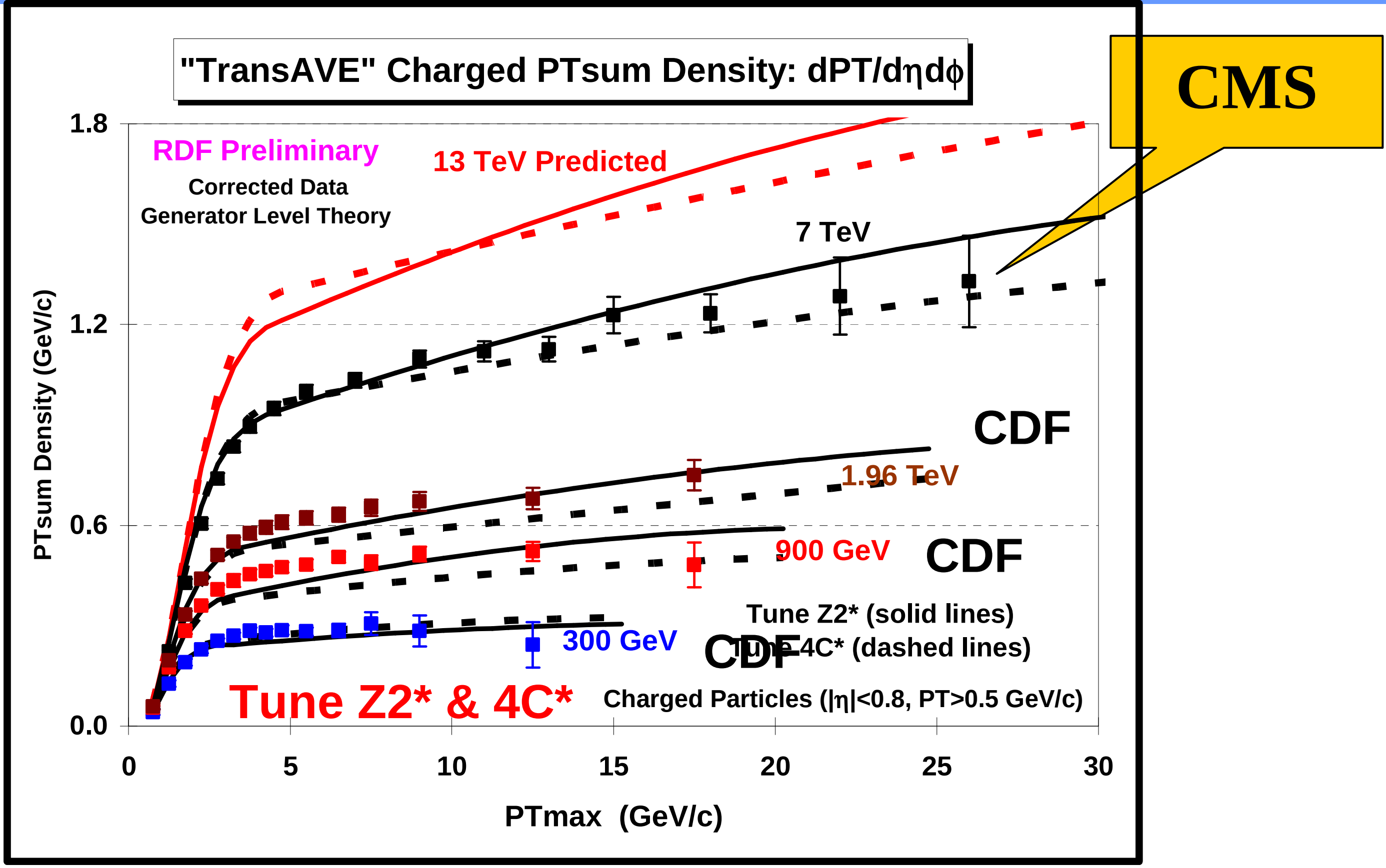
…TeV and CDF data at …GeV to the value …he charged PTsum density in …and "transDIF" regions as …d by …ding charged particle …ax) for c…ed particles with $p_T > 0.5$ …and |η| < … with 5 < PTmax < 6 G…c. The data are plotted versus the ce…r-of-mass energy (*log scale*).

The data are compared …ith PYTHIA Tune Z1 and Tune Z2*.

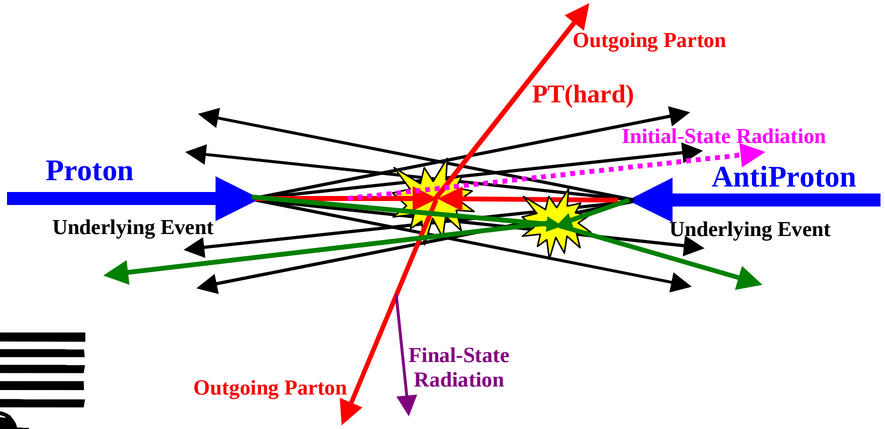
"Tevatron" to the LHC



"Tevatron" to the LHC



New UE Tunes



- **New Herwig++ Tune:** **M. Seymour and A. Siódmok have used the CDF UE data at 300 GeV, 900 GeV, and 1.96 TeV together with LHC UE data at 7 TeV to construct a new and improved Herwig++ tune.**

arXiv:1307.5015 [hep-ph]

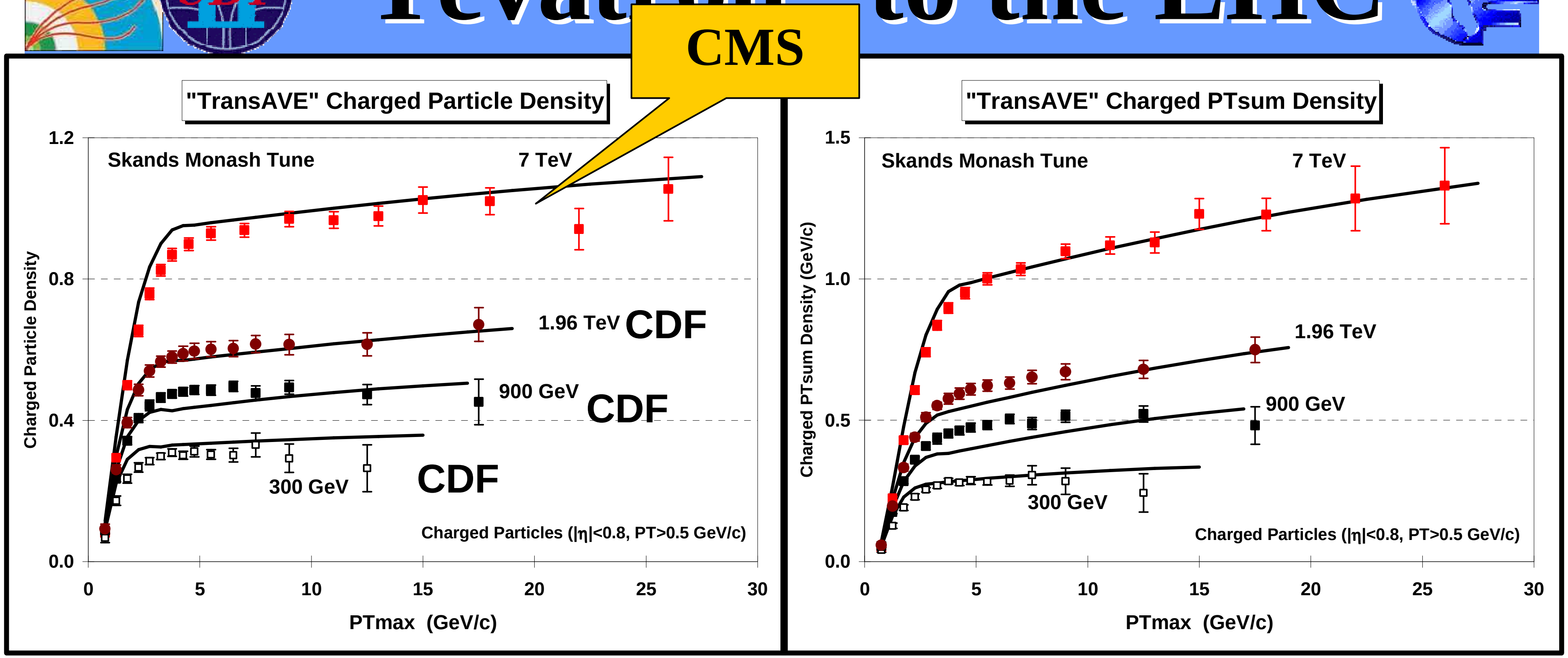
- **New PYTHIA 8 Monash Tune:** **P. Skands, S. Carrazza, and J. Rojo have used the CDF UE data at 300 GeV, 900 GeV, and 1.96 TeV together with LHC data at 7 TeV to construct a new PYTHIA 8 tune (NNPDF2.3LO PDF).**

arXiv:1404.5630 [hep-ph]

- **New CMS UE Tunes:** **CMS has used the CDF UE data at 300 GeV, 900 GeV, and 1.96 TeV together wth CMS UE data at 7 TeV to construct a new PYTHIA 6 tune (CTEQ6L) and two new PYTHIA 8 tunes (CTEQ6L and HERAPDF1.5LO PDF).**

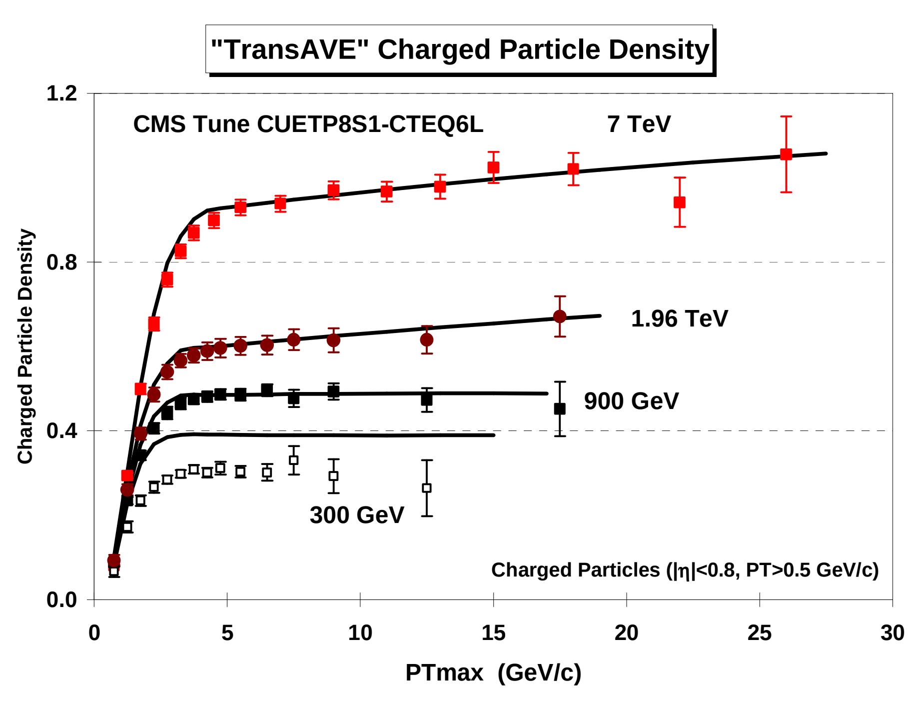
CMS-PAS-GEN-14-001

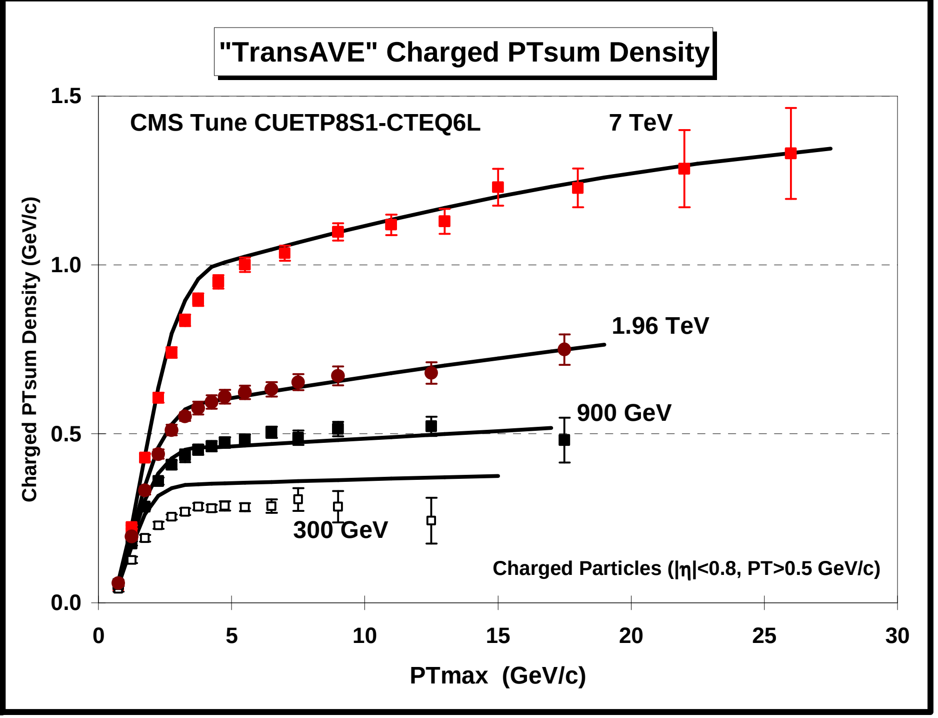
“Tevatron” to the LHC



- **Shows the “transAVE” charged particle density as defined by the leading charged particle, PTmax, as a function of PTmax at 300 GeV, 900 GeV, 1.96 TeV, and 7 TeV compared with the Skands Monash tune.**
- **Shows the “transAVE” charged PTsum density as defined by the leading charged particle, PTmax, as a function of PTmax at 300 GeV, 900 GeV, 1.96 TeV, and 7 TeV compared with the Skands Monash tune.**

"Tevatron" to the LHC

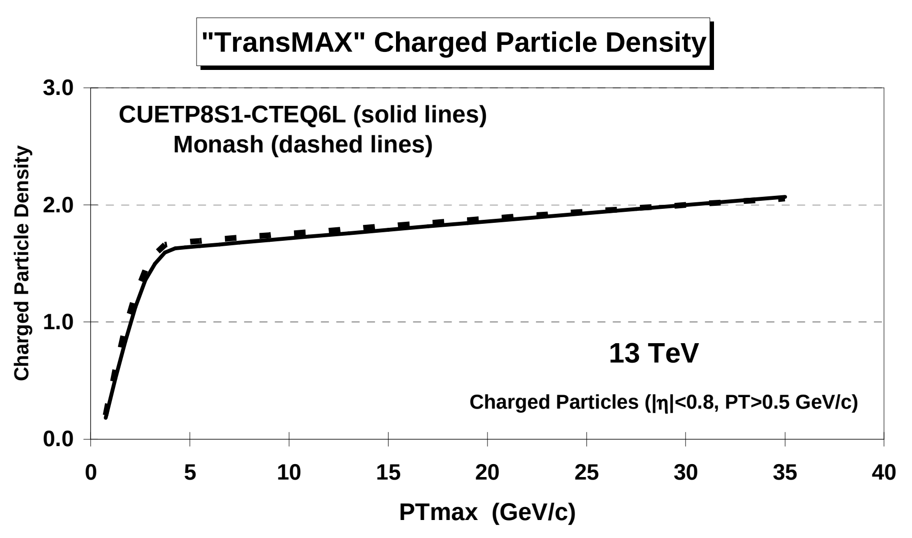


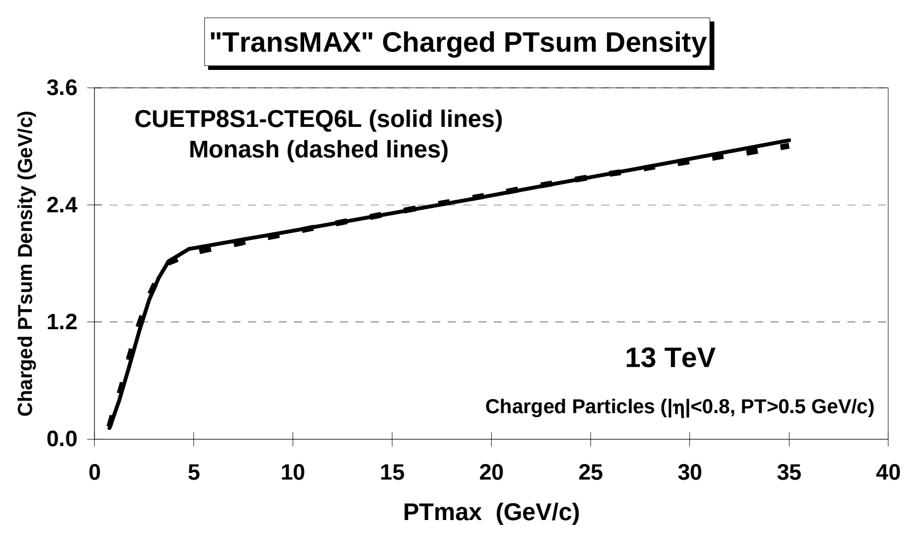


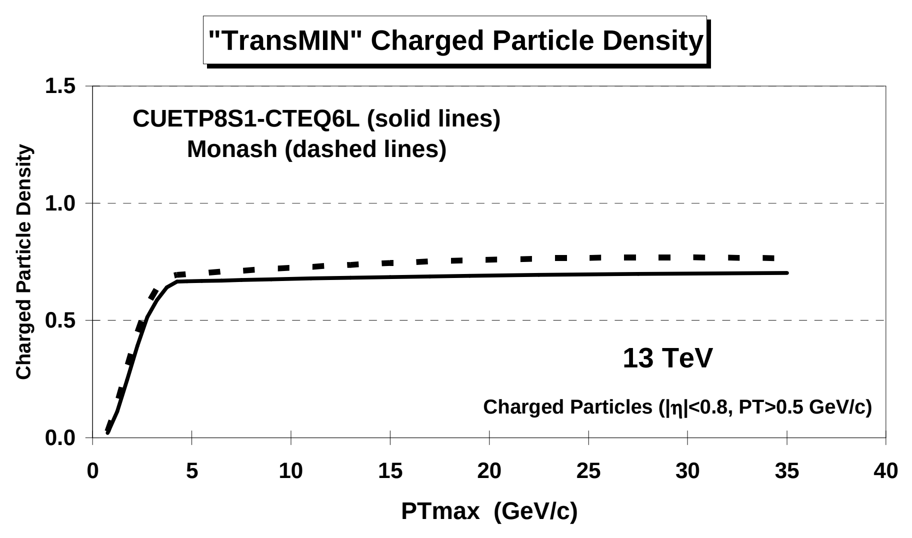
- **Shows the "transAVE" charged particle density as defined by the leading charged particle, PTmax, as a function of PTmax at 300 GeV, 900 GeV, 1.96 TeV, and 7 TeV compared with the CMS tune CUETP8S1-CTEQ6L.**
- **Shows the "transAVE" charged PTsum density as defined by the leading charged particle, PTmax, as a function of PTmax at 300 GeV, 900 GeV, 1.96 TeV, and 7 TeV compared with the CMS tune CUETP8S1-CTEQ6L.**

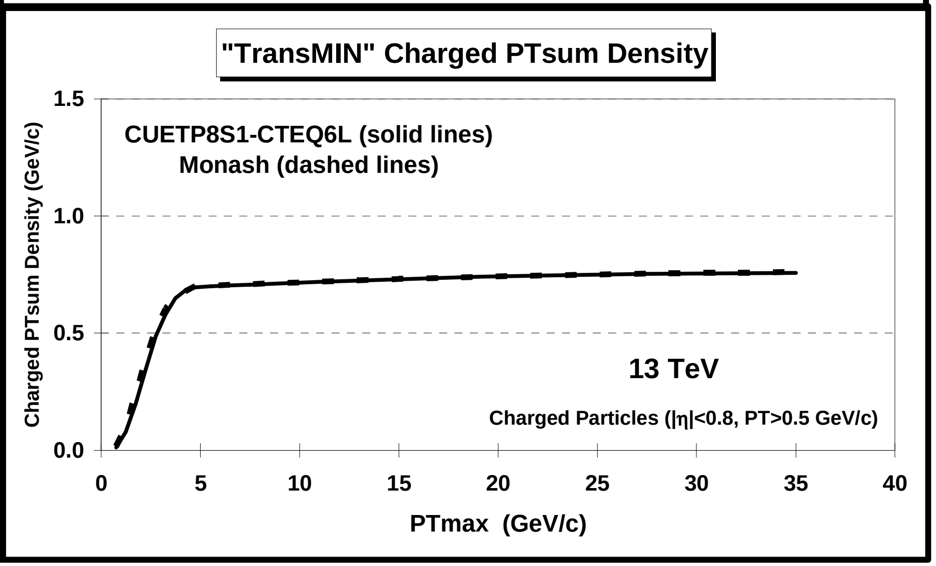
Excludes the 300 GeV data!

Predictions at 13 TeV

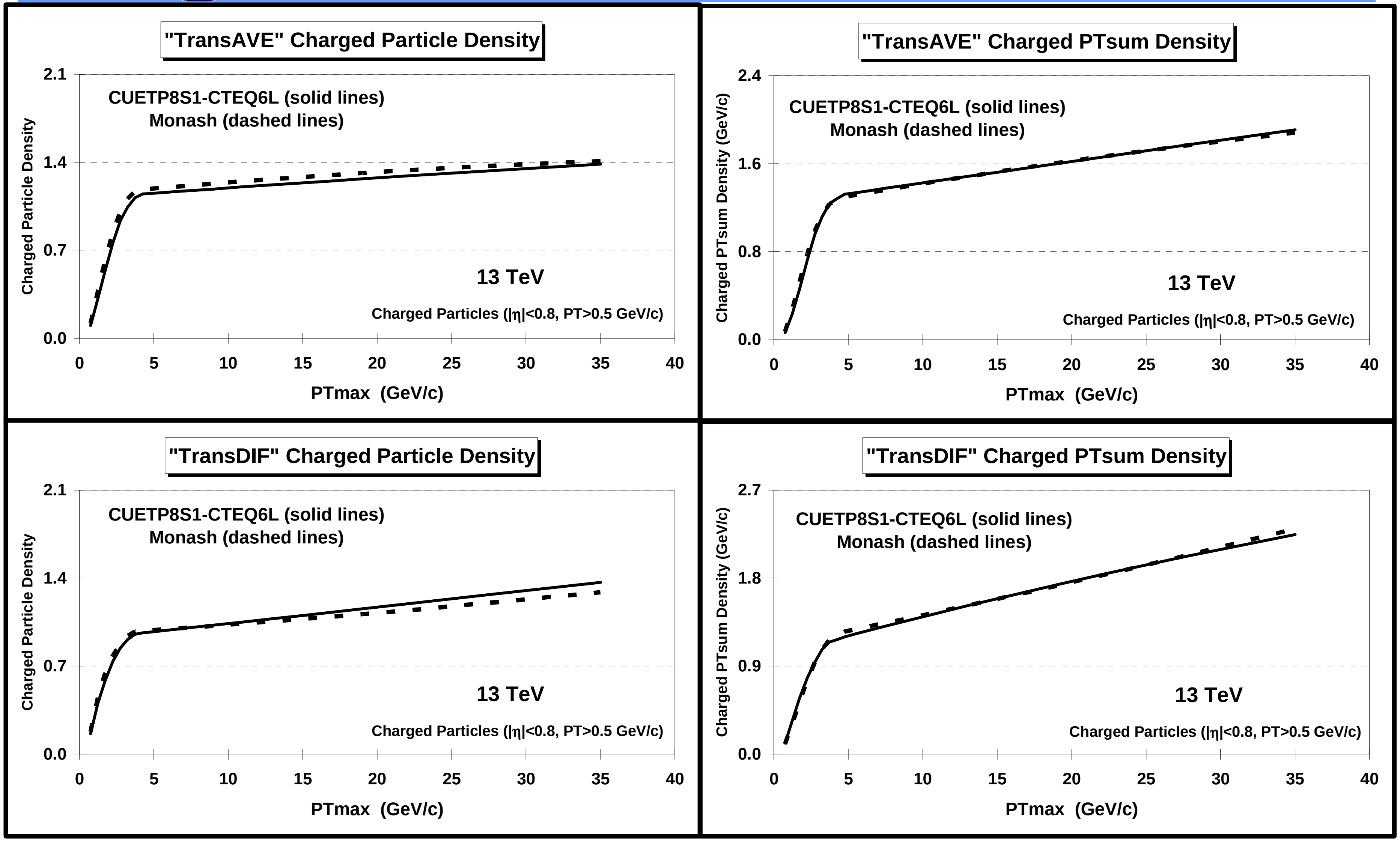




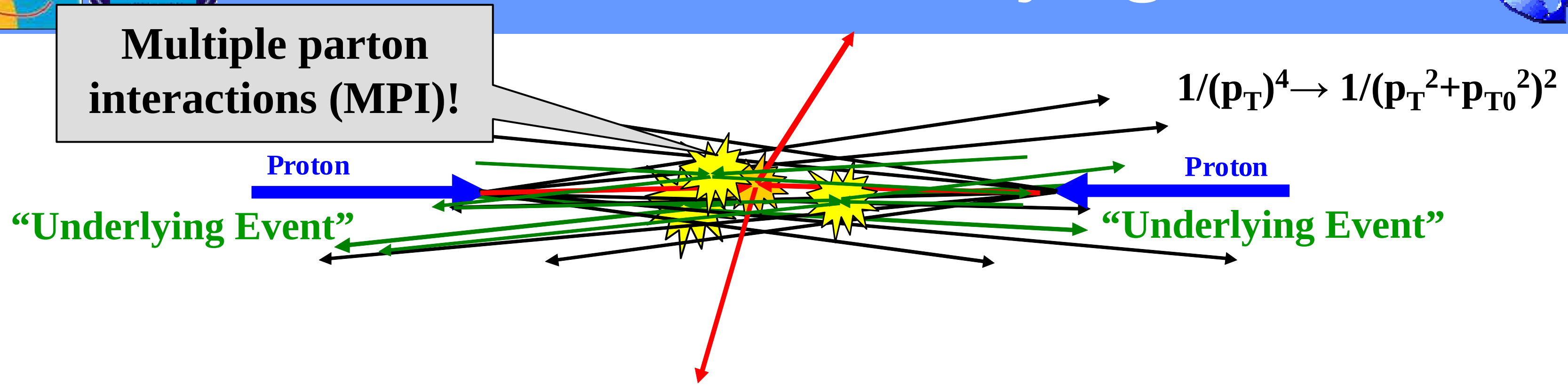




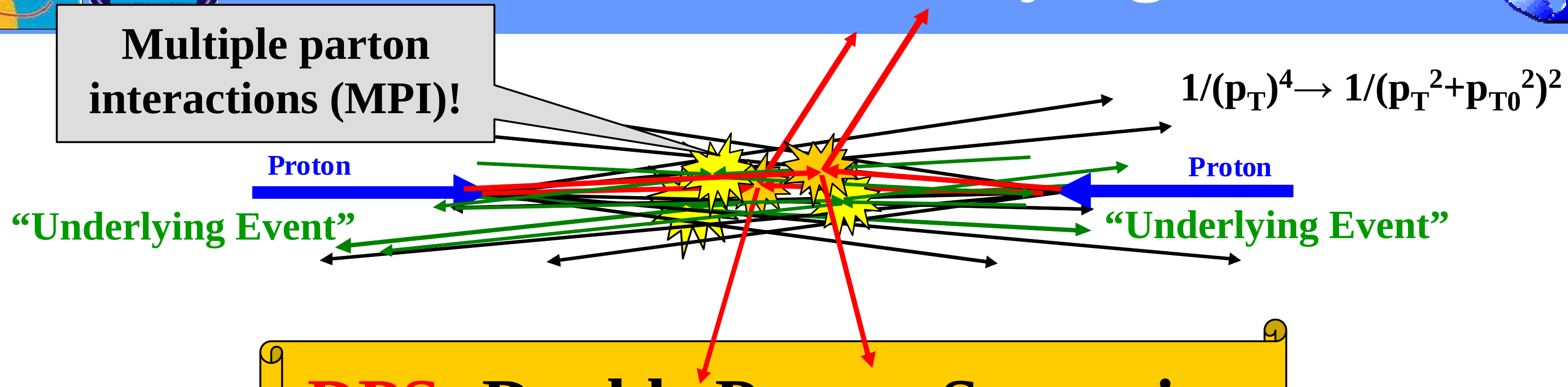
Predictions at 13 TeV



DPS and the "Underlying Event"



DPS and the "Underlying Event"



DPS: Double Parton Scattering

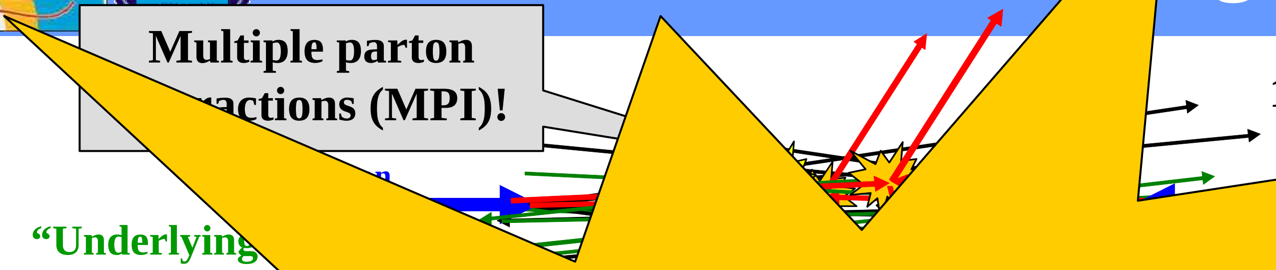
Most of the time MPI are much "softer" than the primary "hard" scattering, however, occasionally two "hard" 2-to-2 parton scatterings can occur within the same hadron-hadron. This is referred to as double parton scattering (DPS) and is typically described in terms of an effective cross section parameter, σ_{eff}, defined as follows:

$$\sigma_{AB} = \frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

Independent of A and B

where σ_A and σ_B are the inclusive cross sections for individual hard scatterings of type A and B, respectively, and σ_{AB} is the cross section for producing both scatterings in the same hadron-hardon collision. If A and B are indistinguishable, as in 4-jet production, a statistical factor of ½ must be inserted.

DPS and the "Underl ng Event"



Having determined the parameters of an MPI model, one can make an unambiguous prediction of σ_{eff}. In PYTHIA 8 σ_{eff} depends primarily on the matter overlap function, which for bProfile = 3 is determined by the exponential shape parameter, expPow, and the MPI cross section determined by p_{T0} and the PDF.

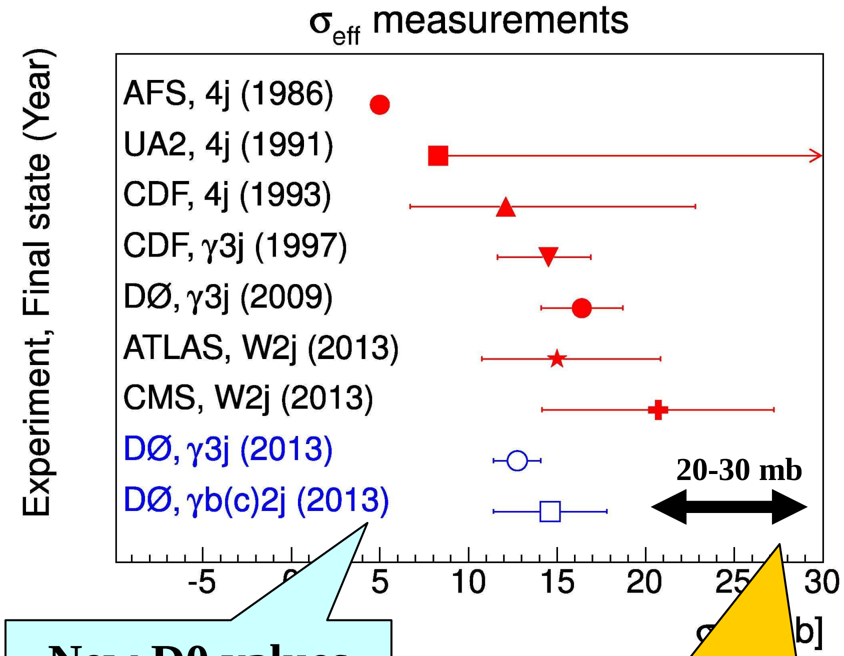
Most of the tim ... however, occasionally two ... n-hadron. Th ... pically described in terms ... ective cross

σ_{eff}

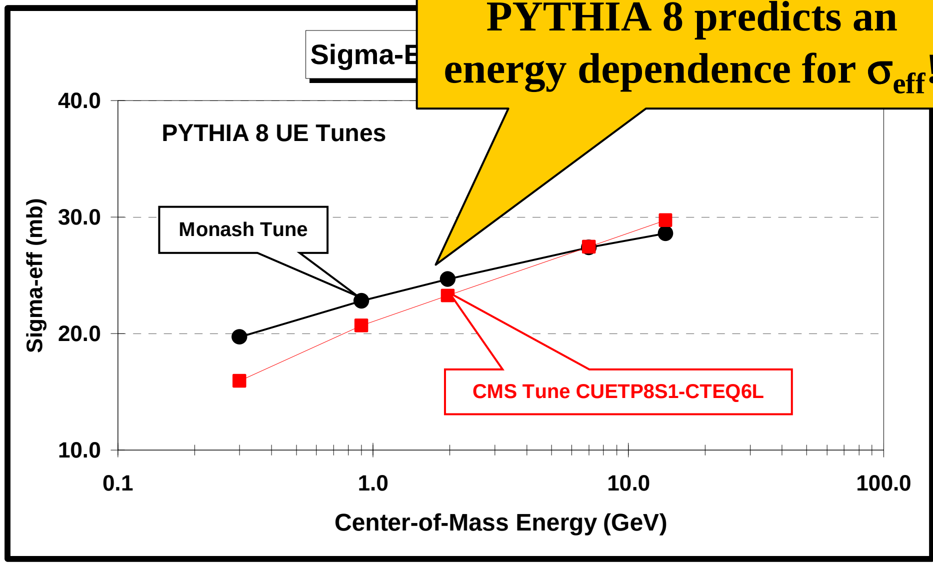
ndependen ... nd B

where σ_A and σ_B are the inclusive ... ections fo ... vidual hard scatterings of type A and B, respectively, and σ_{AB} is the ... section for pr ... ducing both scatterings in the same hadron-hardon collision. If A ... d B are indistinguishable, as in 4-jet production, a statistical factor of ½ must be inser ... d.

Sigma-Effective



New D0 values

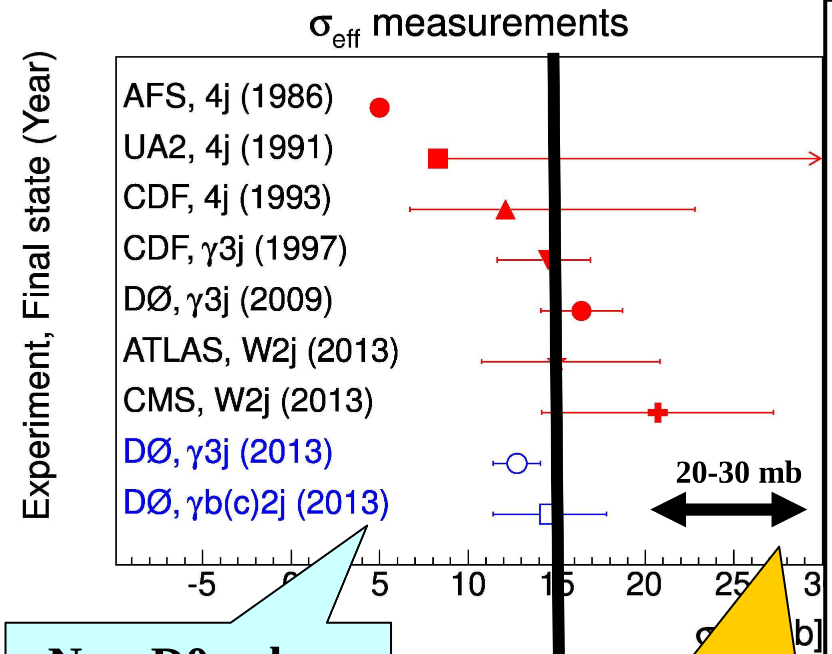


PYTHIA 8 predicts an energy dependence for σ_{eff}!

➡ Shows the σ_{eff} values caluclated from the PYTHIA 8 Monash and CMS tune CUETP8S1-CTEQ6L.

The σ_{eff} predicted from the PYTHIA 8 UE tunes is slightly larger than the direct measurements!

Sigma-Effective



Constraining MPI models using σ_{eff} and recent Tevatron and LHC Underlying Event data

M. H. Seymour[a] A. Siódmok[a]

[a] Consortium for Fundamental Physics, School of Physics and Astronomy, The University of Manchester, Manchester, M13 9PL, U.K.

E-mail: michael.seymour@manchester.ac.uk, andrzej.siodmok@manchester.ac.uk

ABSTRACT: We review the modelling of multiple interactions in the event generator HERWIG++ and study implications of recent tuning efforts to Tevatron and LHC data. It is often said that measurements of the effective cross section for double-parton scattering, σ_{eff}, are in contradiction with models of the final state of multi-parton interactions, but we show that the HERWIG++ model is consistent with both and gives stable predictions for underlying event observables at 14 TeV.

New D0 values

The σ_{eff} predicted from the PYTHIA 8 UE tunes is slightly larger than the direct measurements!

HERWIG++ Tune UE-ee-5-CTEQ6L1 $\sigma_{eff} \approx$ 15 mb!

Summary & Conclusions

- The "transverse" = "transAVE" region is not a true measure of the energy dependence of MPI since it receives large contributions from ISR and FSR.

- The "transMIN" (MPI-BBR component) increases much faster with center-of-mass energy than the "transDIF" (ISR-FSR component)! Previously we only knew the energy dependence of "transAVE".

- PYTHIA 6.4 Tune Z1 & Z2* and PYTHIA 8 Tune 4C* do a fairly good job in describing the energy deperdence of the UE, however there is room for improvement! The parameterization $P_{T0}(E_{cm}) = P_{T0}(E_{cm}/E_0)^{\varepsilon}$ seems to work!

- New tunes are being constructed that describe both the UE and DPS within the same formalism. Stay tuned!

We now have at lot of MB & UE data at 300 GeV, 900 GeV, 1.96 TeV, and 7 TeV! We can study the energy dependence more precisely than ever before!

Summary & Conclusions

- The "transverse" = "transAVE" region is no ... true measure of the energy dependen... of MPI since it r... es large ... butions from ISR and FSR.
- The "transMI... BBR ... ster with center-of-mass energy th... t)! Previously we only knew the ene...
- PYTHI... rly good job in describin... re is room for improvement! ... ns to work!
- New tune... JE and DPS within the sa... formalism.

What we are learning should allow for a deeper understanding of MPI which will result in more precise predictions at the future LHC energies of 13 & 14 TeV!

We no... ave ... of ... UE d... at 300 GeV, 900 ..., 1.96 ..., and 7 Te...! We can stud... e energy ...ependence more prec...ely than ever before!